THIRD
EDITION

Color Atlas of
EMERGENCY TRAUMA

Edited by

Demetrios Demetriades
Carl R. Chudnofsky
Elizabeth R. Benjamin

CAMBRIDGE
Medicine

Color Atlas of Emergency Trauma

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To my late mother Zoe, my father George, my wife Elizabeth, my daughters Alexis and Stefanie, and my son Nicholas.

Demetrios Demetriades

To the newest member of our family, Ayla. The joy that you have brought into our lives is truly amazing.

Carl Chudnofsky

To my father for his never-ending commitment to education and instilling in me a love of learning.

Elizabeth R Benjamin

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Foreword

Every book goes through an evolution of publication, revision, and subsequent editions. It peaks at a point during its publication history, optimizing the knowledge that is delivered. The third edition of the *Color Atlas of Emergency Trauma* is just that – the epitome of a work that has been influential for more than 10 years and has improved with each edition because of the committed focus of the editors of this project since its inception.

The purpose of this atlas is not to replace traditional textbooks, but like much educational content delivery today, it strives to bring knowledge alive with graphics, provide key points that are critical for learners' understanding, and refine subtle points in diagnosis and treatment. The experience this atlas offers is unparalleled, given the legacy of Dr. Demetriades. Dr. Demetriades's personal contribution has spanned more than 30 years caring for trauma patients. The authors highlight pearls of wisdom that can keep people out of trouble. Images and content have been selected with an eye toward modern educational principles: creating that emotional response to learning that occurs through visual and graphic information.

When one reads the contributions of an author/editor like Dr. Demetriades, it is a little bit like hearing of the journeys of a master explorer: talking about the challenges of navigating the unknown, looking for signals to reveal diagnostic truth, and compiling all of the things that can be learned into a visual representation. Only a truly experienced master surgeon can accomplish this task. One who is fortunate enough to learn from such an individual can benefit tremendously from his or her perspective. We can all benefit from Dr. Demetriades's contributions through this book.

This atlas is a legacy and a personal diary detailing one of the largest accumulated experiences of caring for trauma patients in existence. Everybody caring for trauma patients will benefit from utilizing this important contribution.

David B. Hoyt, MD, FACS
Executive Director, American College of Surgeons

Preface

Management of the severely injured patient requires an experienced team of trauma surgeons, emergency physicians, physician specialists, nurses, and technicians working together in harmony to save a life. In the third edition of the *Color Atlas of Emergency Trauma*, our team of experienced, highly skilled trauma practitioners from one of the busiest trauma centers in the United States has reviewed, revised, and updated the content to bring you the most relevant compendium of trauma images available in a single easy-to-use resource. The reader will immediately see that all drawings have been redone in a fresh new style, and many new high-quality images have been added, bringing the total number of images to more than 1,200. Our team has also added step-by-step instructions for many of the procedures commonly performed during trauma resuscitation. Each procedure is accompanied by drawings and photographs that make the reader feel like they are right there at the bedside. Our team has also called upon their decades of experience to provide procedure "pearls" and "pitfalls" that every clinician will want to know. The third edition of the *Color Atlas of Emergency Trauma* is essential for anyone who provides trauma care or trauma education. The authors hope that you will enjoy using it as much as we enjoyed creating it.

Chapter

1

Head Injury

Demetrios Demetriades and Elizabeth R. Benjamin

Introduction

Head trauma is the most common cause of death and permanent disability following trauma. Blunt head injury is usually the result of motor vehicle collisions, auto versus pedestrian collisions, or falls from significant heights. Gunshot wounds cause the vast majority of penetrating head injuries, although stab wounds and impalement injuries may also be seen.

Clinical Examination

Head injury is classified into mild, moderate, and severe categories, depending on the patient's Glasgow Coma Scale (GCS) at the time of presentation.

Patients with mild head injury have a GCS of 14–15, those with moderate head injury have a GCS of 9–13, and those with severe head injury have a GCS of <9. The GCS is a physiologic score and does not provide information about the anatomic nature of the injury. It can be affected by hypotension, hypoxia, hypoglycemia, medications, and alcohol and illicit drug use. The anatomic severity of head trauma is described by the head Abbreviated Injury Score (AIS), which is based on the computed tomography (CT) scan, magnetic resonance imaging (MRI), and operative findings. A head AIS of 1 or 2 indicates minor brain trauma, an AIS of 3 indicates moderate trauma, an AIS of 4 or 5 denotes severe trauma, and an AIS of 6 describes a nonsurvivable injury.

Following the primary and secondary survey according to Advanced Trauma Life Support (ATLS) protocols, a more specific head injury evaluation should be performed. The head is inspected for signs of trauma, including lacerations, hematomas, areas of skull depression, raccoon eyes, Battle's sign, hemotympanum, rhinorrhea, and otorrhea. The pupils are examined for symmetry and reaction to light, the extraocular movements and other cranial nerve functions are assessed, and motor and sensory function is assessed for symmetry or deficiencies.

Patients with brain stem herniation present with depressed levels of consciousness; dilatation of the ipsilateral pupil, due to compression of the third cranial nerve (in the early stages, there may be transient pupil constriction due to stimulation of the nerve); contralateral motor posturing (decorticate, followed by decerebrate and finally flaccid paralysis); bradycardia; elevated blood pressure; and irregular respiration.

Investigations

All patients with a GCS of <14, or patients with a GCS of 15 with a history of loss of consciousness, amnesia, headache, posttraumatic seizure, scalp hematoma, signs suspicious of fracture of the base of the skull (ecchymoses around the eyes or behind the ears, ear or nose bleeding, or cerebrospinal fluid leakage), significant mechanism, advanced age, or history of anticoagulation, should undergo noncontrast CT scan evaluation. Selected patients may require further investigation by CT angiography (CTA), MRI, or rarely cerebral angiography. The ability to perform 3-D or multiplanar reconstructions may be particularly helpful in the diagnosis of injuries like basilar skull fractures.

Multitrauma patients may have injuries to the chest or abdomen that require immediate operative intervention for bleeding control, which takes priority over head-injury evaluation. In these cases, the CT scan of the head may be deferred until after the hemorrhage control.

CTA should be performed in suspected vascular injuries, such as in the presence of fractures of the vertebral canal or the carotid foramen, or in neck hematomas following blunt trauma, such as seat-belt marks.

Skull X-rays are seldom indicated because CT scan is more sensitive for identifying skull fractures and provides more information regarding underlying brain injury. If CT scan is not available, skull X-rays may be useful for identifying foreign bodies (e.g., bullet fragments) or intracranial air.

General Management

The main goal of cerebral resuscitation in the emergency department is to prevent secondary brain damage, by preventing or correcting any hypoxia, hypotension, seizures, hyperthermia, and hypercarbia. Cerebral resuscitation is performed in the context of overall resuscitation and is guided by ATLS principles. Securing an airway and ensuring adequate oxygenation and ventilation are the highest priorities. A brief neurologic examination should be performed prior to using paralytic drugs for rapid sequence intubation (RSI). Patients with a GCS <9 should be evaluated for intubation, and selected patients with a higher GCS may also need intubation for airway protection.

The cerebral perfusion pressure (CPP) is defined as the mean arterial pressure (MAP) minus the intracranial pressure (ICP) and is a reflection of the blood flow and oxygen delivery to the brain. Maintaining adequate CPP (CPP >70 mmHg in adults, CPP >50 mmHg in young children) is important in the face of increased ICP to prevent secondary ischemic injury.

Consequently, measures to decrease ICP while maintaining adequate systemic blood pressure with resuscitation and hemorrhage control are essential.

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Consequently, measures to decrease ICP while maintaining adequate systemic blood pressure with resuscitation and hemorrhage control are essential.

For patients with evidence of increased ICP or clinical signs of actual or impending herniation, immediate measures to decrease ICP are indicated. The patient should be adequately sedated and, if necessary, pharmacologically paralyzed. Hyperventilation to reduce pCO2 to a level of 32–35 mmHg may temporarily decrease intracranial pressure. Mannitol administration (0.5–1.0 g/kg over 20 minutes) may be considered in hemodynamically stable patients with no suspicion of significant extracranial bleeding. In cases where potential hypotension and hemorrhage are of concern, mannitol should be avoided and consideration should be given to the use of hypertonic saline (3% NaCl, 250 ml). The neck should be cleared of any binding or restricting devices or ties to improve venous drainage from the head. Positioning the head at 30 degrees elevation can decrease ICP once the spine has been cleared. If the patient has spinal precautions, head-of-bed elevation can be achieved with reverse Trendelenburg positioning. The placement of a ventriculostomy to drain cerebrospinal fluid (CSF) is often effective for treating elevated ICP. In refractory cases, barbiturate coma may be used to decrease cerebral metabolic demand. In extreme cases, a decompressive craniectomy or even lobectomy may be considered.

Hyperthermia should be avoided, as this significantly increases cerebral metabolism and oxygen demand. Seizure prophylaxis (phenytoin loading dose 10–15 mg/kg over 30–60 minutes, followed by 5 mg/kg per day or levetiracetam 500 mg twice a day for 7 days) in all patients with intracranial hemorrhage is recommended.

Definitive treatment for head injury depends on the nature of the lesion. Closed skull fractures require no specific treatment, but open fractures should be irrigated, debrided, and closed. Depressed skull fractures require elevation of the fragment if the displacement is greater than one bone width, along with debridement if the wound is grossly contaminated. Basilar skull fractures usually heal uneventfully, but patients with rhinorrhea or otorrhea require precautions and careful follow-up to ensure that the fistula closes. Most CSF leaks stop within two weeks, but persistent leaks may require a formal dural closure.

Most intracranial injuries can be managed nonoperatively, with supportive measures. Smaller lesions are usually managed with observation and repeat CT scan, usually after about six hours or earlier if the patient deteriorates.

As a general guideline, adults with epidural hematomas (EDH) diameter >15 mm, subdural hematomas (SDH) >10 mmHg, or a midline shift >5 mm require a craniectomy. Subarachnoid hemorrhage (SAH) is treated nonoperatively and in severe cases with nimodipine (calcium channel blocker) to decrease surrounding vasospasm. Intraventricular hemorrhage (IVH) may require ventriculostomy to remove blood and CSF, but the prognosis usually remains poor.

ICP monitoring should be considered in patients with a GCS <9 plus an intracranial pathology on CT scan or in patients with a GCS <9 and normal CT scan, if two or more of the following are present: (a) age >40, (b) BP <90, and (c) posturing. In addition to the diagnostic value, an ICP catheter may be used for therapeutic purposes, to drain CSF and lower the intracranial pressure.

Tips and Pitfalls

- Some patients are at a higher risk for intracranial hemorrhage after relatively minor mechanisms of injury. These include the elderly, chronic alcoholics, infants, patients with cerebral atrophy, and patients on antiplatelet or anticoagulant medications. A low threshold for obtaining a head CT scan should be maintained in these patients.
- Pediatric patients with a GCS of 15 and scalp hematoma should be evaluated by CT scan or observed for at least six hours because of the risk of EDH.
- Altered mental status, seizures, and focal neurologic deficits should not be ascribed to intoxication, dementia, or other chronic conditions if there is a history or evidence of head trauma present.
- Excessive hyperventilation (pCO2 <30 mmHg) should be avoided because it results in cerebral vasospasm and decreased brain perfusion.
- Subacute SDH may appear isodense with the surrounding brain 5–10 days after the injury. Altering the density values of the CT or using contrast will demonstrate the lesion.
- Coagulopathy is common with serious head injury and may result in more severe bleeding, hemorrhage from other noncerebral sites, and dysregulation of the coagulation cascade. A baseline coagulation profile should be obtained in all patients with serious head injury and repeated periodically during admission. Appropriate blood products and reversal agents should be administered early.
- Child abuse should be suspected in cases of intracerebral injury or skull fracture in infants and children.

Scalp Injuries

The scalp is composed of five layers: skin, dense connective tissue, loose connective tissue, aponeurosis, and epicranium. The vessels and nerves are located in the dense connective tissue. Scalp lacerations can bleed profusely because of the rich vascularity and the position of the vessels in the dense connective tissue, which limits retraction and constriction when bleeding. It is important to suture or staple any scalp laceration and apply a compression dressing as soon as possible following the primary survey. Injection of local anesthetic should be done in the dense connective tissue and should be met with significant resistance. If there is no resistance during injection, most likely the anesthetic is infused into the loose connective tissue layer, which does not contain any nerves, and it will not be effective. Scalp lacerations usually heal well and rarely get infected because of the rich blood supply (Figure 1.1).

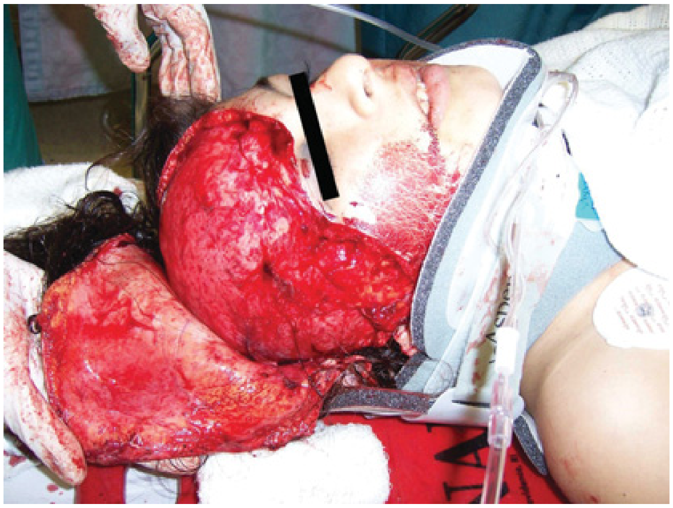

Figure 1.1 Major avulsion of the scalp. Perform extensive irrigation, reapproximation with sutures or staples, followed by a compression dressing. These wounds heal well because of the excellent blood supply of the scalp.

Skull Fractures

Skull fractures are often associated with intracranial injury, and specific locations, such as those across the middle meningeal arterial groove or the dural sinuses, can be of particularly high risk for EDH. CT scan has largely replaced plain radiographs of the skull for diagnosis due to the high sensitivity of CT scan for detection of fractures. The incidence of brain injury in the setting of a skull fracture is high and occurs in about one-third of the patients. Skull fractures in infants are commonly due to child abuse, and the circumstances surrounding the injury need to be carefully investigated.

As with fractures of other boney structures, skull fractures are classified as simple or comminuted, displaced or nondisplaced, and open or closed. Linear fractures are the most common, accounting for approximately 80% of all skull fractures, and generally result from lower-energy blunt trauma over a large surface area. In contrast, comminuted fractures contain multiple fracture lines and generally require a larger amount of force to create compared to linear fractures. Displaced fractures are the result of a very-high-energy direct blow to a small surface area. Patients with depressed skull fractures have an increased incidence of posttraumatic seizures because the impact of the fragments on the cortex of the brain results in areas of trauma that may ultimately become seizure foci. Consequently, seizure prophylaxis is begun on admission and continued for one week. The management of closed depressed skull fractures depends on the degree of depression. Conservative treatment is usually recommended for closed fractures with minor depression; however, surgical elevation of the fragments is usually recommended if the depression is greater than one bone width (from inner to outer table) (Figure 1.2 A–C, Figure 1.3 A,B, Figure 1.4, Figure 1.5 A–D).

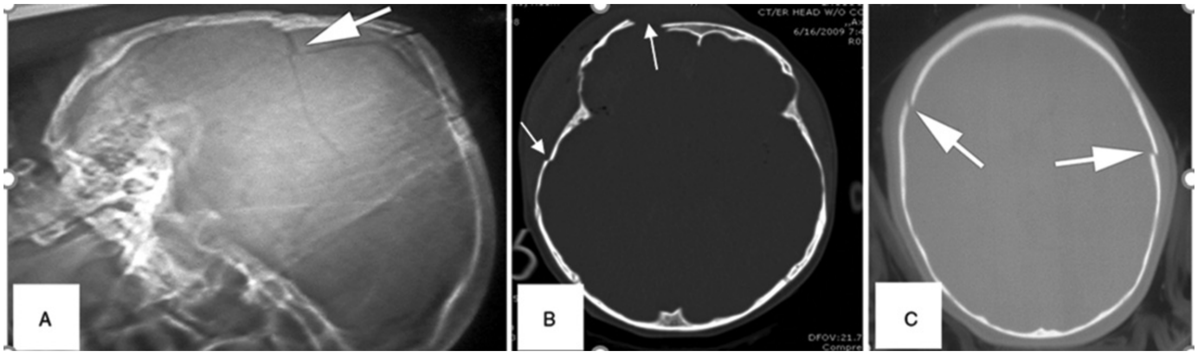

Figure 1.2 A–C Skull fractures. Lateral skull radiograph showing a comminuted fracture of the apex of the skull (arrow; A). CT scan showing a displaced fracture of the skull (arrows; B). CT scan showing right frontal and left parietal skull fractures with minimal displacement (arrows; C).

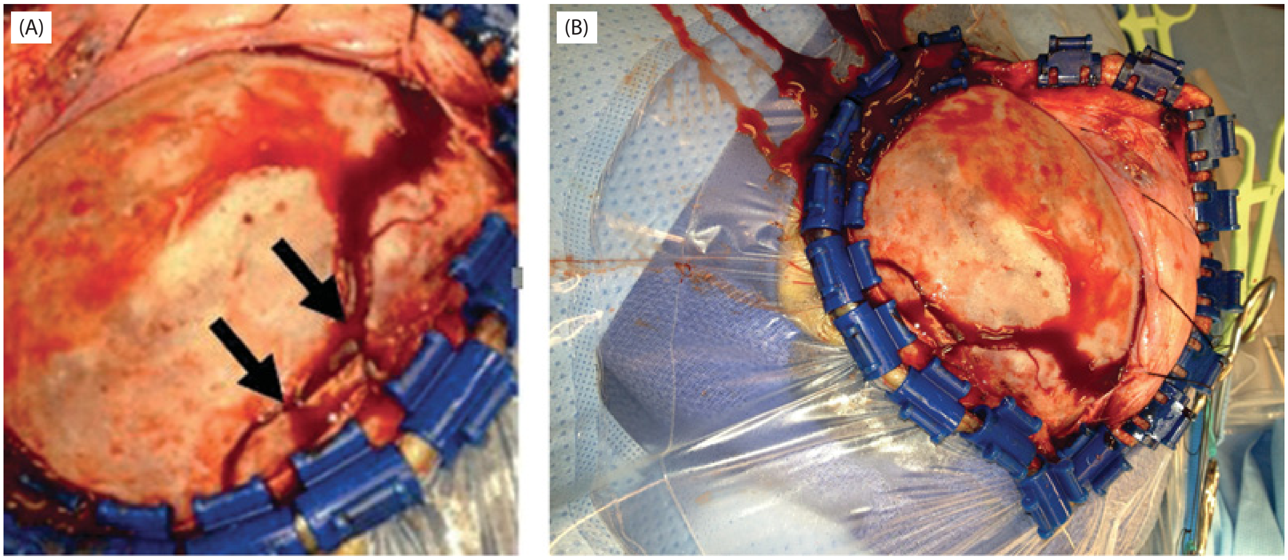

Figure 1.3 A,B Linear fractures of the skull. Intraoperative appearance of a linear fracture of the temporal bone (A). Intraoperative appearance of a linear fracture of the vault of the skull (B).

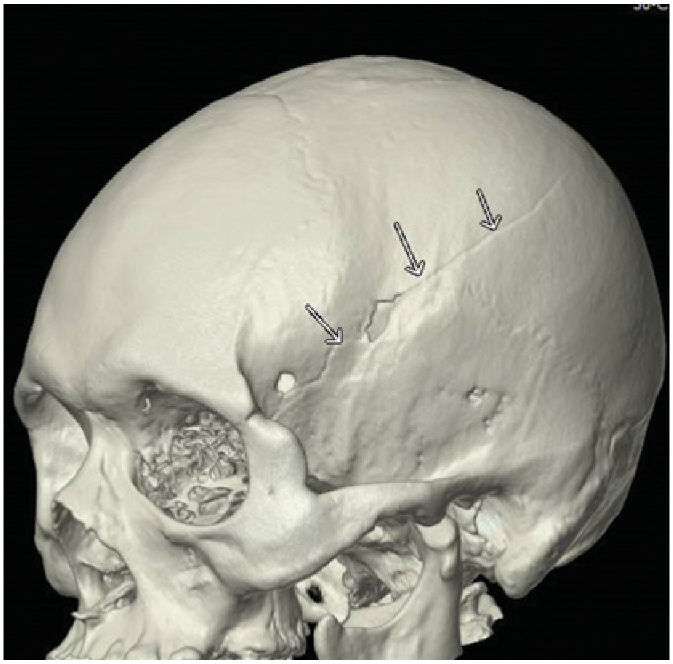

Figure 1.4 Linear skull fracture crossing the middle meningeal artery is often associated with large EDH.

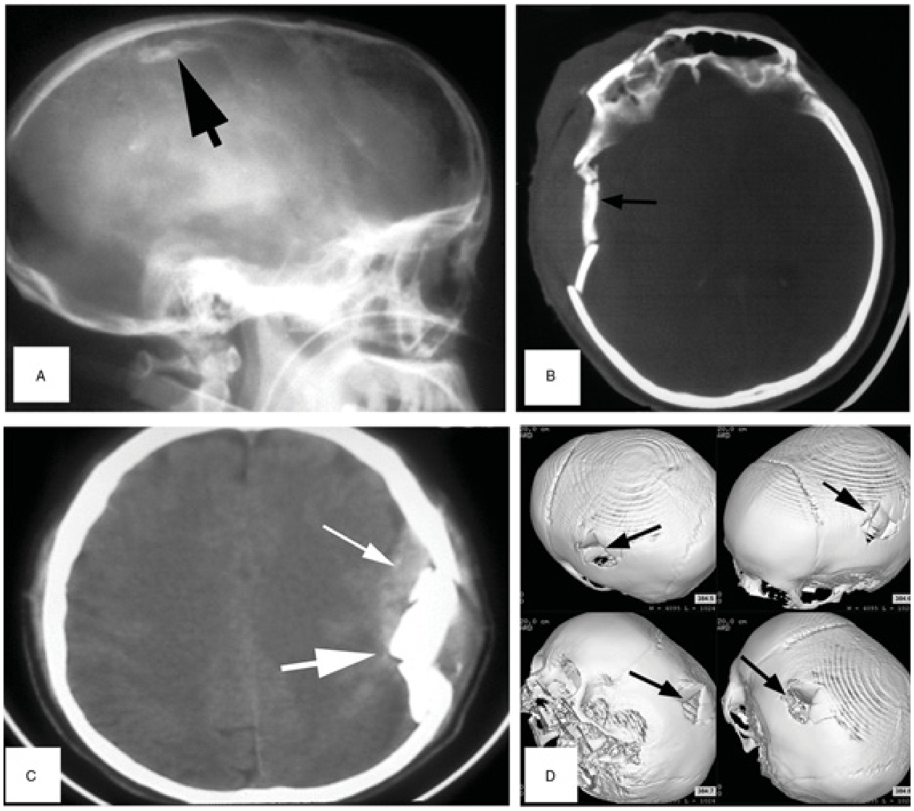

Figure 1.5 A–D Depressed skull fractures. Lateral radiograph of the skull showing hyperdensity due to overlapping bone fragments (arrow) at the apical–parietal skull (A). CT scan showing right temporoparietal comminuted depressed fracture (arrow) and associated soft tissue swelling. This patient suffered a concomitant EDH (B). CT scan showing depressed fracture of the left parietal bone (large arrow) with underlying EDH (small arrow; C). CT scan showing 3-D reconstruction of a skull with left parietal depressed comminuted skull fracture (arrow; D).

Open fractures that communicate with the skin or mucus membranes may result in the direct introduction of contaminants such as hair, skin, or foreign debris into the cranial vault. Pneumocephalus (air within the confines of the skull) rarely results in mass effect and displacement of intracranial contents. More commonly, its significance is the presence of a direct communication between the brain and the extracranial environment, which may lead to the development of meningitis, osteomyelitis, or, more commonly, brain abscess. Consequently, open skull fractures must be carefully debrided, irrigated, and closed to prevent such complications. Prophylactic antibiotics are indicated for the treatment of open skull fractures (Figure 1.6).

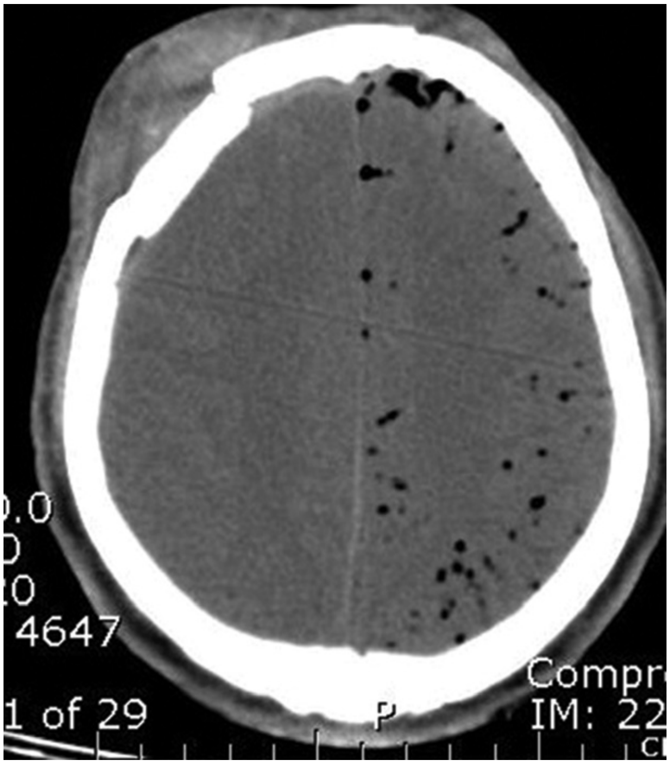

Figure 1.6 Open skull fractures: CT scan of a patient with an open skull fracture and extensive pneumocephalus.

Isolated skull fractures may result in headache and local tenderness. Physical examination of the skull may reveal a depression in the skull, but more commonly, the fracture is not palpable because of overlying soft-tissue swelling.

Basilar Skull Fracture

The skull base is divided into three compartments (anterior, middle and posterior fossa), and the clinical presentation of a basilar fracture varies depending on location. Anterobasilar fractures may present with raccoon eyes (hematomas around the eyes), rhinorrhea, and anosmia; middle fossa fractures may present with hemotympanum, otorrhea, vertigo, or Battle's sign (ecchymosis of the skin behind the ear); posterior fossa fractures may present with ataxia and nystagmus. Raccoon eyes and Battle's sign may develop over time, despite being absent on initial presentation (Figure 1.7 A,B, Figure 1.8 A–C).

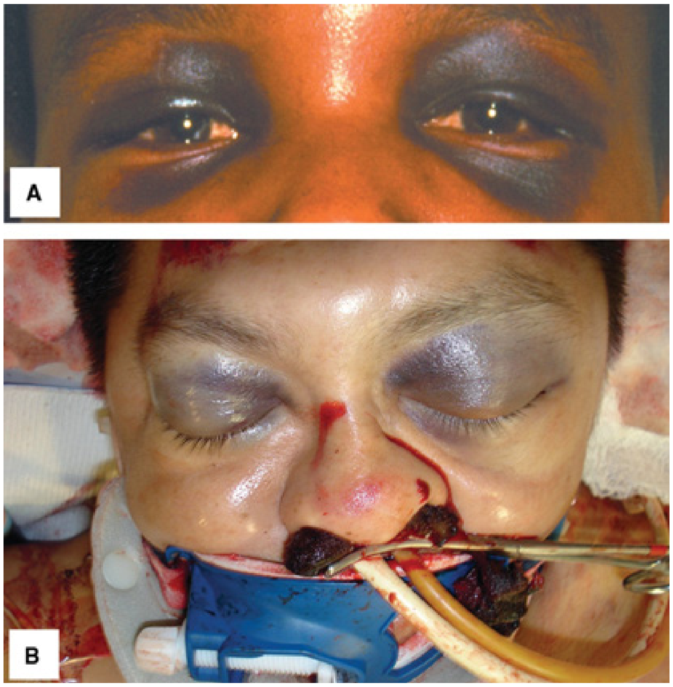

Figure 1.7 A,B Physical examination findings indicative of basilar skull fracture of the anterior cranial fossa. Patient with bilateral periorbital ecchymosis (raccoon eyes), due to fracture of the base of the anterior skull fossa (A). Bilateral raccoon eyes and massive epistaxis in a patient with severe basilar skull fracture (B).

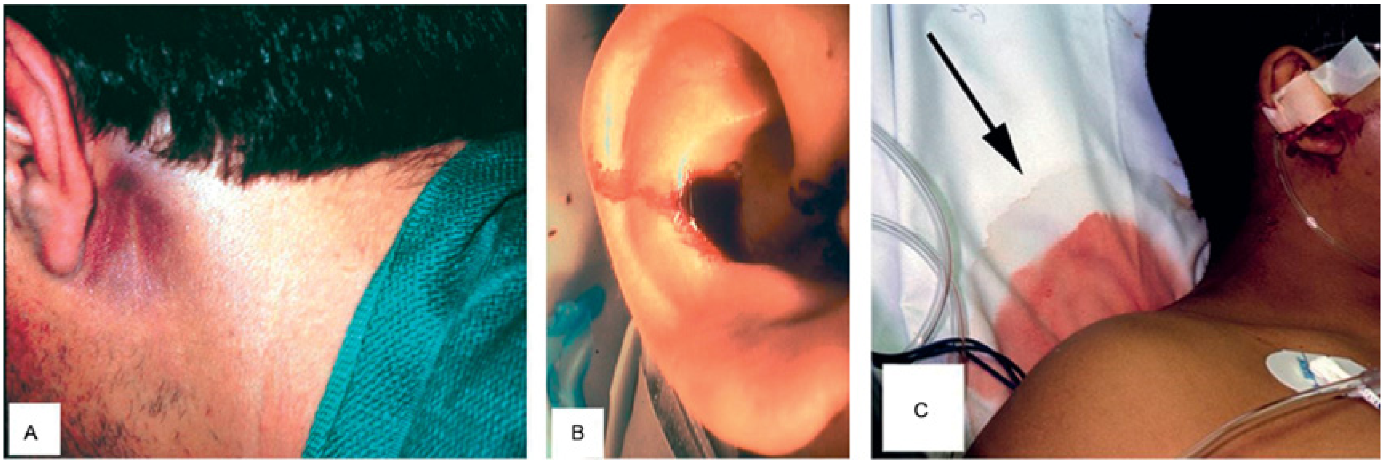

Figure 1.8 A–C Physical exam findings indicative of basilar skull fracture of the middle cranial fossa. Battle's sign – ecchymosis over the mastoid process, indicating basilar fracture involving the middle cranial fossa (A). Bloody otorrhea following basilar skull fracture of the middle cranial fossa with rupture of the tympanic membrane (B). Bloody otorrhea, reveals the "halo effect" or "double ring sign" (arrow) of CSF separating from blood when applied to the sheet (C). This sign can also be seen when the bloody drainage is applied to a paper towel or filter paper.

A careful neurologic exam is also required, as the cranial nerves can be injured as they exit the skull base. Basilar fractures may be associated with a tear of the underlying dura, resulting in CSF leakage and rhinorrhea or otorrhea. If the tympanic membrane remains intact, hemotympanum may be seen. Although meningitis can ensue from a persistent CSF leak, prolonged prophylactic antibiotics are not indicated. About 90% of the dural tears heal within one week. Persistent leakage beyond two weeks may require operative repair with a dural patch (Figure 1.9 A,B, Figure 1.10).

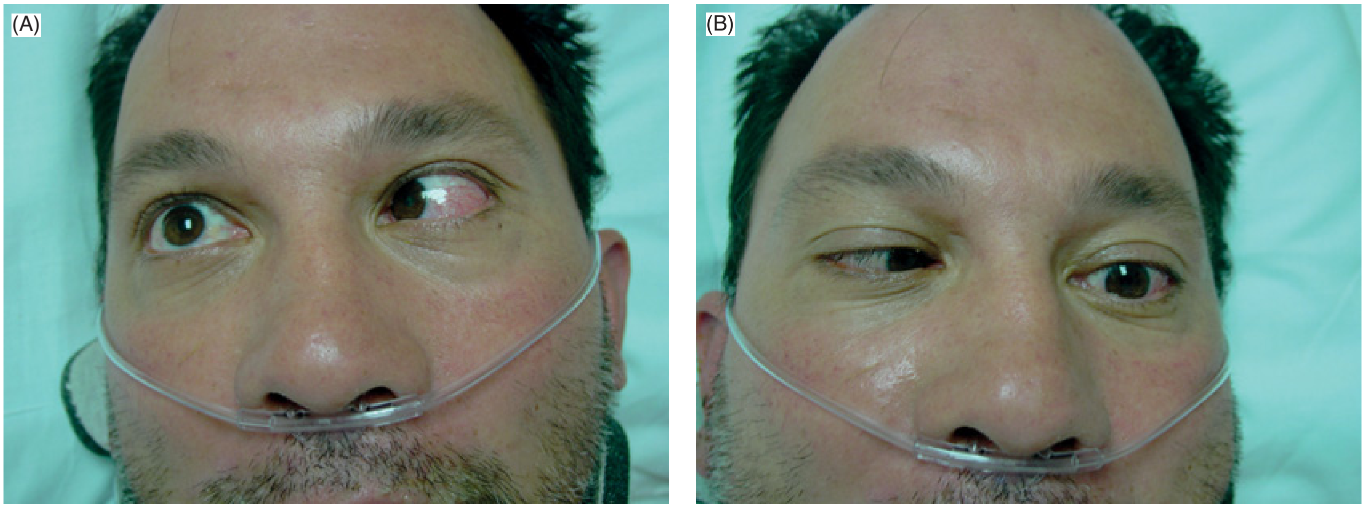

Figure 1.9 A,B Patient with basilar skull fracture and right abducens nerve (cranial nerve VI) paralysis, presenting with diplopia. The right eye cannot gaze laterally (A) and when gazing forward it develops medial strabismus (B).

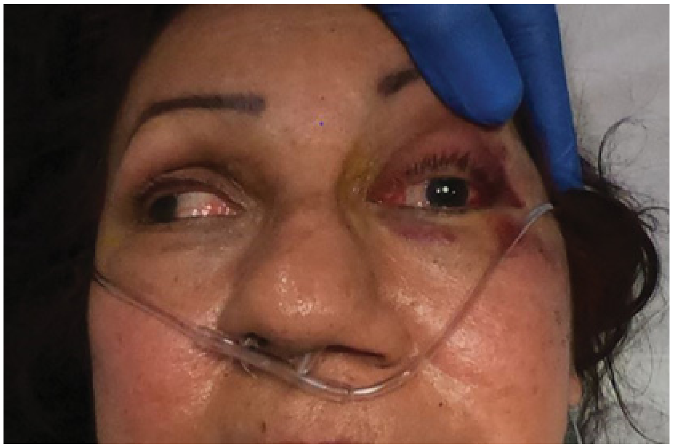

Figure 1.10 Fracture base of the skull with left oculomotor nerve (cranial nerve III). The patient had diplopia, ptosis, mydriasis, and inability for medial gaze.

Basilar skull fractures are diagnosed primarily using CT scan. The sensitivity of standard CT scan for basilar skull fractures is lower than for fractures of the rest of the cranium, and special views with thin cuts may be needed for accurate diagnosis.

The treatment of a basilar skull fracture is conservative unless there is a cranial nerve compression, which requires surgical decompression. In the presence of a basilar fracture in the anterior cranial fossa, a nasogastric tube should never be inserted due to the risk of inadvertent placement of the tube in the brain. In these cases, an orogastric tube is preferable. Also, bag-valve mask ventilation in the presence of an anterior fossa basal fracture can cause massive pneumocephalus (Figure 1.11 A,B, Figure 1.12 A,B).

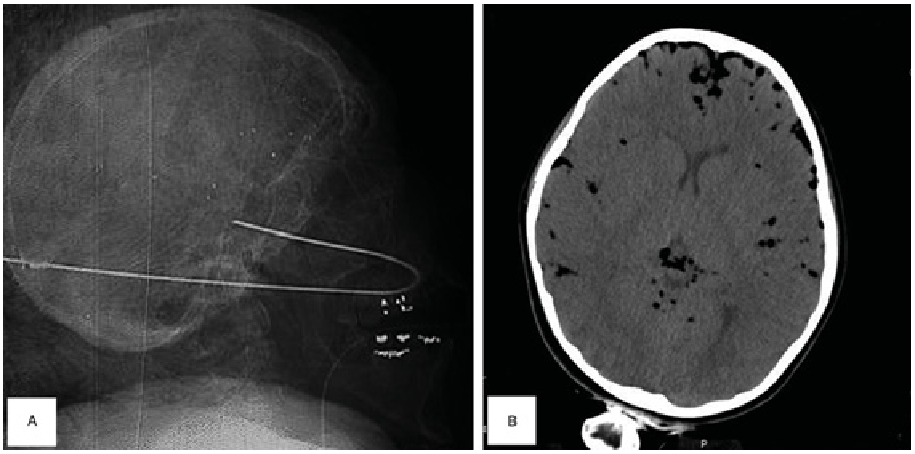

Figure 1.11 A,B Iatrogenic complications in basilar skull fractures. Plain X-ray showing a nasogastric tube inserted in the brain through a fracture of the anterior cranial fossa (A). In the presence of such fractures, an orogastric tube should be inserted. CT scan with significant amounts of pneumocephalus following fracture base of the skull and use of bag-valve mask by the paramedics (B).

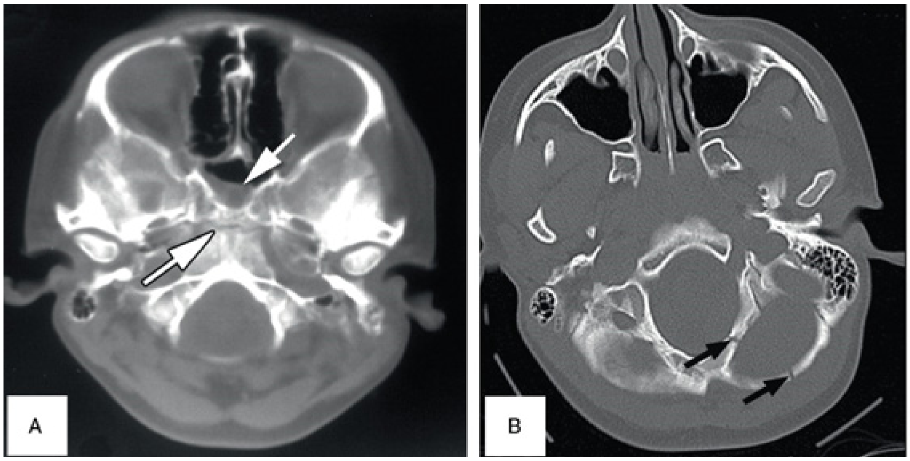

Figure 1.12 A,B Radiological diagnosis of fractures of the base of the skull. CT scan of the base of the skull showing a basilar skull fracture (bottom arrow) and isolated air–fluid level in the sphenoid sinus (top arrow), which is characteristic of basilar skull fracture (A). CT scan with occipital basilar skull fractures (B).

Intracranial Hematomas

Epidural Hematoma

EDH accounts for approximately 10–15% of severe head injuries, with the peak incidence in young adult males between the ages of 15 and 24. Common etiologies include motor vehicle collisions, auto versus pedestrian, and sports injuries. The typical EDH is unilateral and occurs as a result of a temporoparietal skull fracture that transects the course of the middle meningeal artery. Another source of bleeding is injury to the venous sinuses. Blood accumulates outside the dura mater, dissecting the dura from the inner table of the skull, and compresses the underlying brain as it expands (Figure 1.13).

The classic clinical pattern is that of an initial head trauma with loss of consciousness, followed by a lucid interval, with a subsequent decrease in the level of consciousness due to mass effect from the accumulating EDH. However, only 30% of patients with EDH demonstrate this classical pattern, and approximately 8% of EDHs are detected after a significant delay. Many patients, particularly pediatric patients, are asymptomatic, without headache, amnesia, or loss of consciousness, and have deterioration several hours after injury (Figure 1.14 A–C).

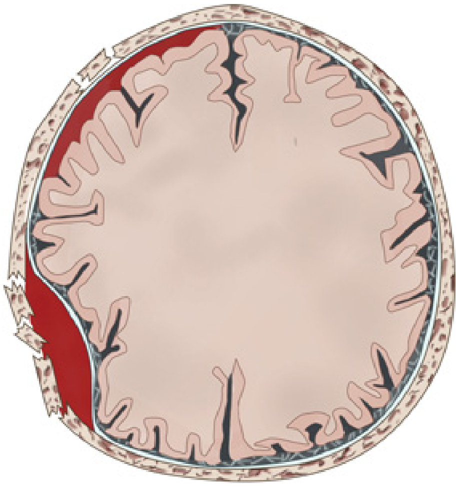

Figure 1.13 Illustration of EDH and SDH: The EDH is lenticular in shape located between the skull and the dura mater. The SDH is crescent-shaped and located between the dura matter and the brain parenchyma.

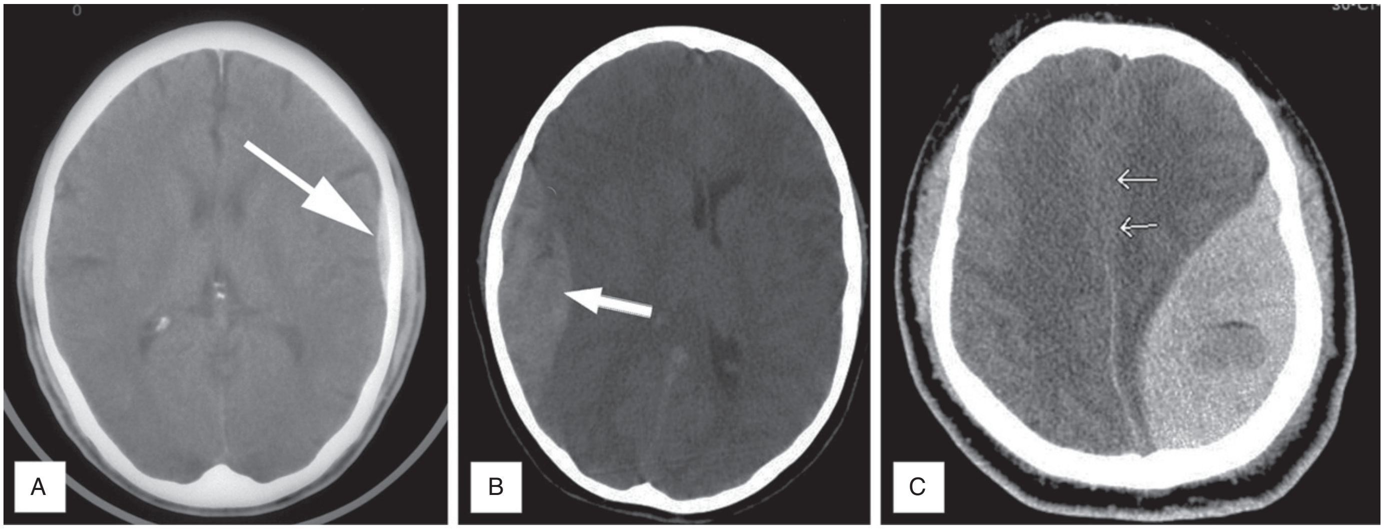

Figure 1.14 A–C EDH: Subtle left parietal EDH without mass effect (A). Large EDH in the right parietal area (arrow) with narrowing of right ventricle and midline shift (B). EDH: Massive EDH with severe midline shift (C).

The diagnosis of EDH is based on CT scan. CT scan reliably demonstrates the typical hyperdense accumulation of blood in a lenticular shape at the periphery of the cerebrum, indenting the cerebral cortex and brain parenchyma. Outside of the posterior fossa, the hematoma will not cross suture lines, as the dura is tightly adhered at these fixed points. CT scan is indicated in patients who have a history of head injury with loss of consciousness, GCS <15, headache, or scalp hematoma. CT scan findings may be subtle in patients with severe anemia (lowering the density of the hematoma on CT scan), hypotension (which reduces the rate of arterial blood loss), or if the CT scan is obtained too soon after the trauma, prior to significant accumulation of blood (Figure 1.15 A–C).

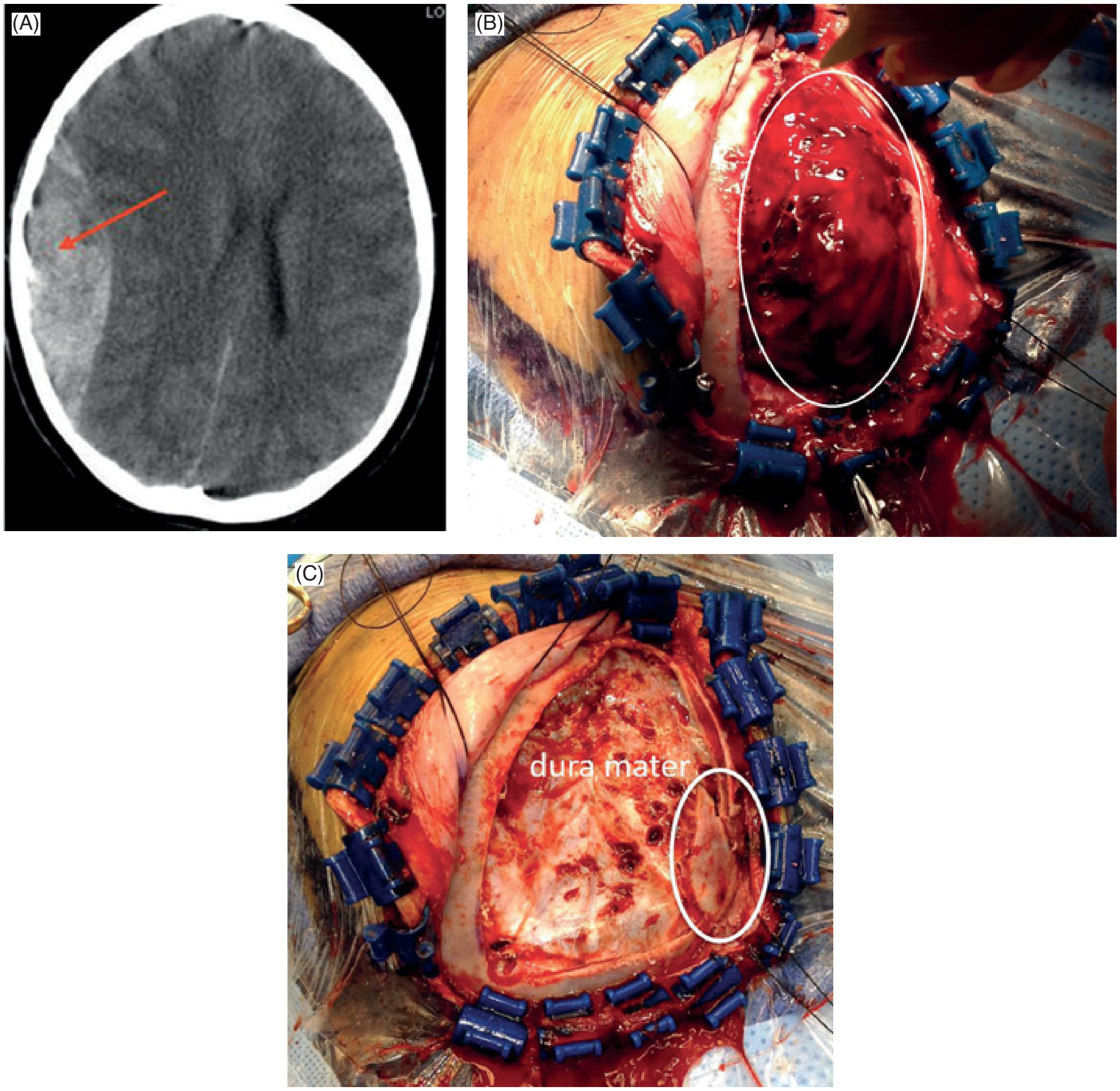

Figure 1.15 A–C Large right EDH with mixed densities (arrows), suggestive of active bleeding (A). Intraoperative appearance of a large EDH after removal of the skull. The hematoma is on top of the dura mater (B). The dural membrane appears intact after evacuation of the EDH (circle shows a skull fracture; C).

The treatment of a significant EDH, usually >15 mm in diameter in adults, is surgical evacuation of the clot and ligation of the bleeding vessel or repair of the dural sinus laceration. The prognosis is excellent in isolated EDH if the diagnosis and treatment are made early.

Subdural Hematoma

SDH is divided into three categories, based on the time elapsed since the injury. These categories are acute SDH (0–24 hours), subacute SDH (1–7 days), and chronic SDH (>7 days). The importance of this distinction is that the appearance of the hemorrhage on CT scan varies with time as it moves from a solid hyperdense clot (acute SDH) to an intermediate or isodense phase, in which the hematoma is often indistinguishable from adjacent normal brain tissue (subacute SDH). After approximately 5–10 days, a chronic phase begins, in which the cellular elements of the hematoma break down and are reabsorbed, leaving a fluid-filled encapsulated hypodense mass (chronic SDH). Radiographic interpretation has to take these sequential changes into account.

SDH accounts for approximately 40% of severe head injury. It is found in all age groups, but certain populations are at higher risk for SDH, including the elderly, chronic alcoholics, patients who are anticoagulated, and infants (shaken baby syndrome). Symptoms of SDH depend on multiple variables, including the size and location of the SDH, the rate of accumulation of blood, the degree of underlying brain injury, the extent of cerebral atrophy, and the premorbid level of functioning.

Acute SDH results from either a direct blow to the head resulting in cortical brain damage and bleeding or acceleration/deceleration forces causing avulsion of the bridging veins from the dura to the surface of the brain, resulting in accumulation of blood under the dura. This collection of blood is seen on CT scan as a hyperdense semilunar (crescent-shaped) hematoma that conforms to the convexity of the cerebral hemisphere. Depending on the size of the hematoma and the degree of underlying cerebral edema, a mass effect will occur, with obliteration of the ventricles and cisterns and shift of cerebral structures across the midline that may culminate in transtentorial herniation. Because of underlying cortical damage, patients will often demonstrate contralateral focal neurologic deficits consistent with the location of the SDH. Additional symptoms include altered mental status, headache, nausea and vomiting, and symptoms related to increased intracranial pressure (Figure 1.16 A–C, Figure 1.17 A–E).

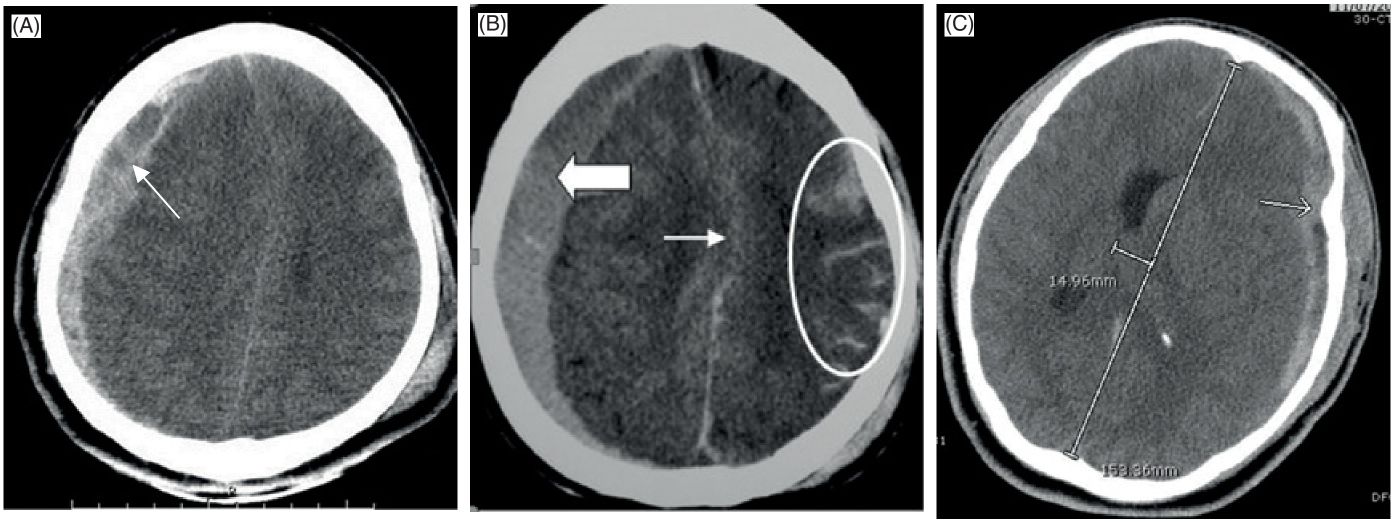

Figure 1.16 A–C CT scans of SDH. Right SDH (arrow) with significant midline shift (A). Large right SDH (large arrow) associated with major midline shift (small arrow), and left subarachnoid hemorrhage (circle; B). Left subdural hematoma (arrow) with significant midline shift of nearly 1.5cm (C).

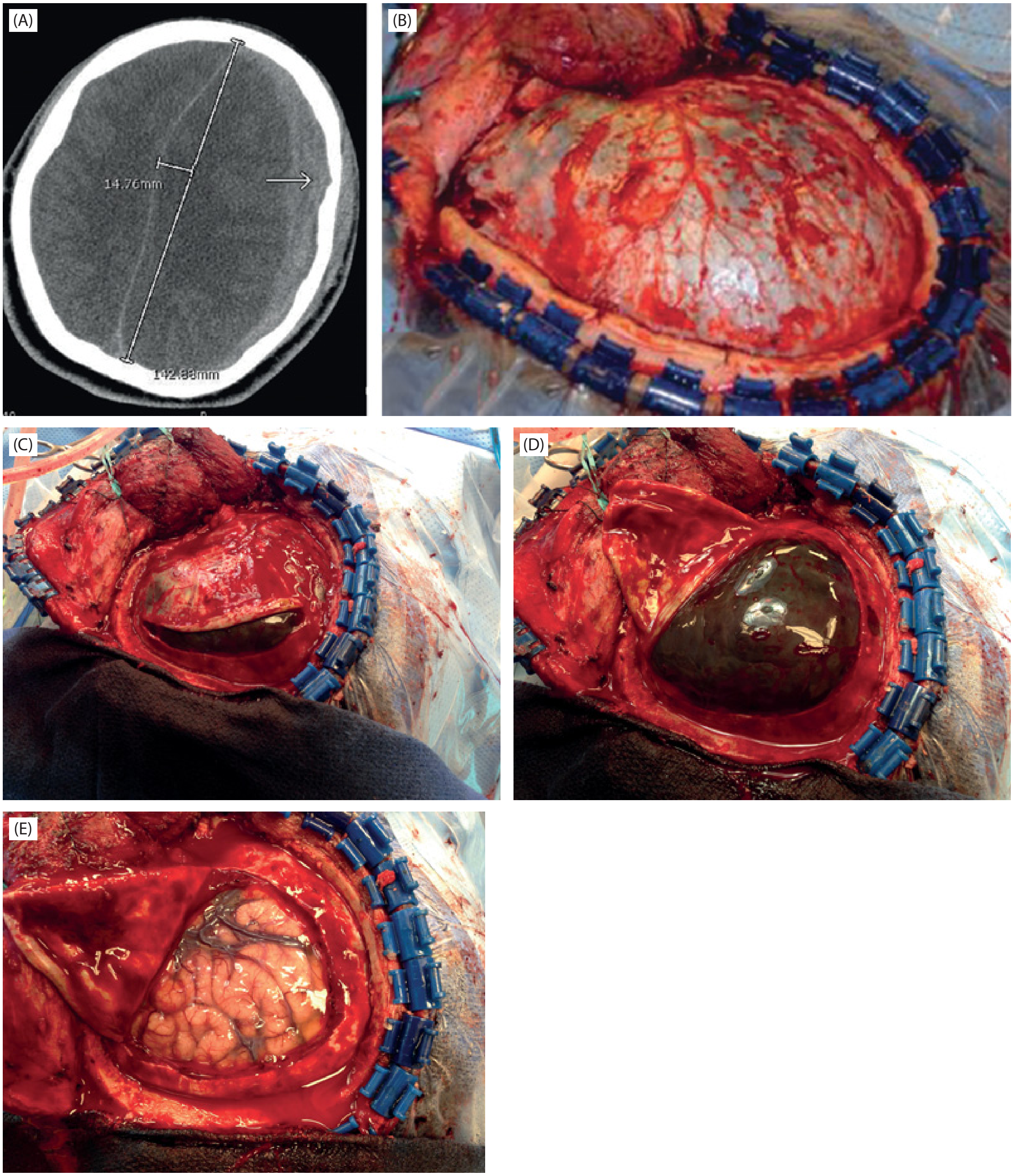

Figure 1.17 A–E Acute SDH. Large left acute SDH with midline shift (A). Intraoperative appearance of a large acute SDH, after removal of the cranium. Note the intact and tense dura mater with engorged vasculature (B). Incision of the dura shows an underlying large acute SDH (C). Appearance of SDH after wide opening of the dural membrane (D). Normal brain parenchyma after evacuation of the SDH (E).

As the process of resorption continues, the SDH enters a chronic phase. The SDH releases osmotically active cellular elements as it breaks down, causing the hematoma to expand. Symptoms may be very subtle or may be suggestive of increased intracranial pressure. Chronic SDH occurs more commonly in elderly patients with significant preexisting cerebral atrophy, so that changes in mental state, such as increasing confusion, disorientation, lethargy, and depression, may make SDH difficult to detect. CT scan reveals a hypodense semilunar collection of fluid with a surrounding hyperdense capsule and variable amounts of cellular debris in the dependent portion of the SDH. There is a high risk of rebleeding into a chronic SDH, and a sudden decompensation may be the presenting complaint when this occurs. Rebleeding is seen as a hyperdense collection of blood superimposed on an encapsulated chronic hematoma (Figure 1.18 A,B, Figure 1.19 A,B).

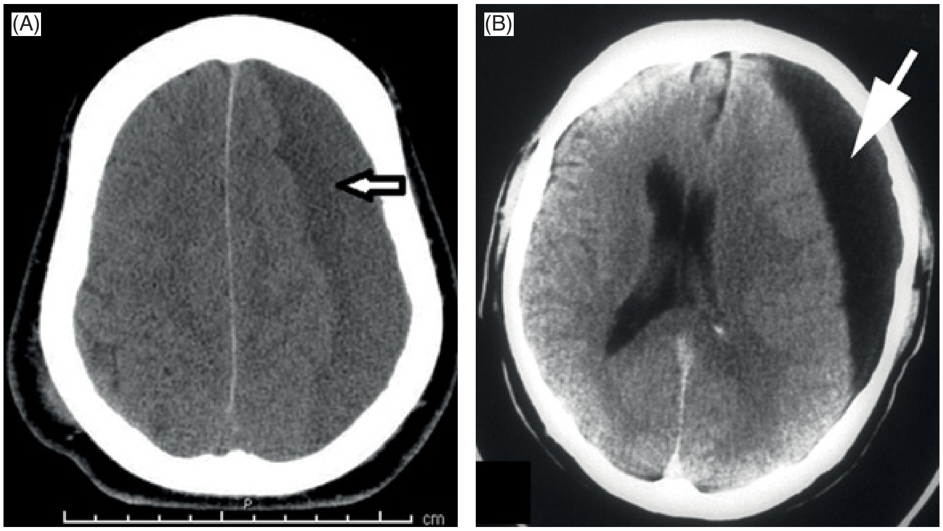

Figure 1.18 A,B Chronic SDH. Chronic left SDH (arrow) without mass effect (A). Large chronic left SDH (arrow) with mass effect and compression of the left ventricle (B).

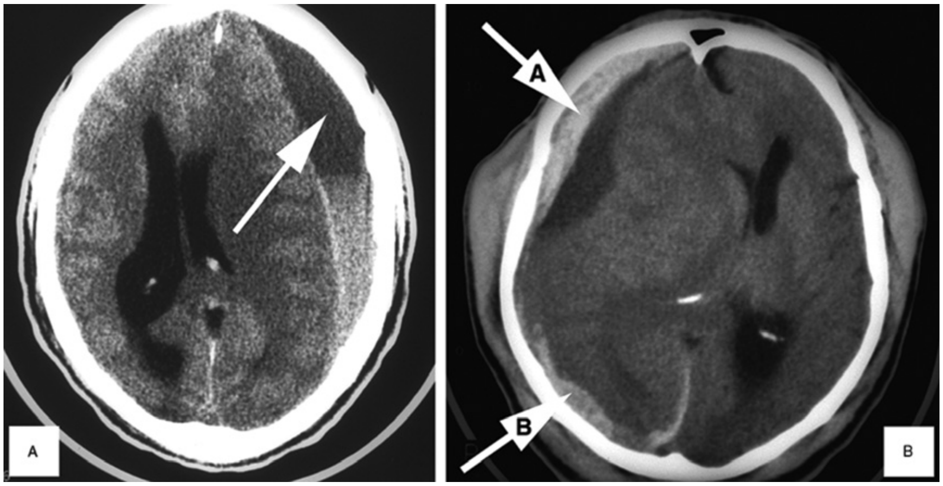

Figure 1.19 A,B Acute on chronic SDH: Axial image of acute on chronic SDH. The acute hemorrhage can be seen in the dependent (lower) aspect of the SDH and the chronic collection at the top (arrow). Note the significant midline shift (A). Acute rebleeding (high density) in a chronic (black density) right frontal SDH (arrow) and occipital areas (arrow) with midline shift (B).

Treatment for a large SDH (usually >10 mm in diameter in adults) in the acute or subacute stages is evacuation via craniotomy. Small hematomas can be managed conservatively with close neurologic observation and serial CT scan evaluation. The decision regarding management of a chronic SDH depends on the premorbid function of the individual, size of the SDH, and current symptoms. Seizure prophylaxis should be given to all cases for the first week to decrease the incidence of early post-traumatic seizures.

Traumatic Subarachnoid Hemorrhage

Many SAH occur spontaneously as a result of a rupture of an arteriovenous malformation (AVM) or berry aneurysm. However, head trauma can also result in SAH. SAH appears as a hyperdense collection of blood that tracks along the outer edge of the brain parenchyma beneath the arachnoid membrane. On CT scan, SAH may be subtle and is seen as fingerlike white projections tracking into the sulci. SAH is often associated with other traumatic intracranial pathology, which can complicate the clinical presentation. The symptoms of isolated SAH can include headache, altered level of consciousness, nausea, vomiting, tachycardia, fever, and neck rigidity. The symptoms can depend on the location and size of the hemorrhage (Figure 1.20 A–D).

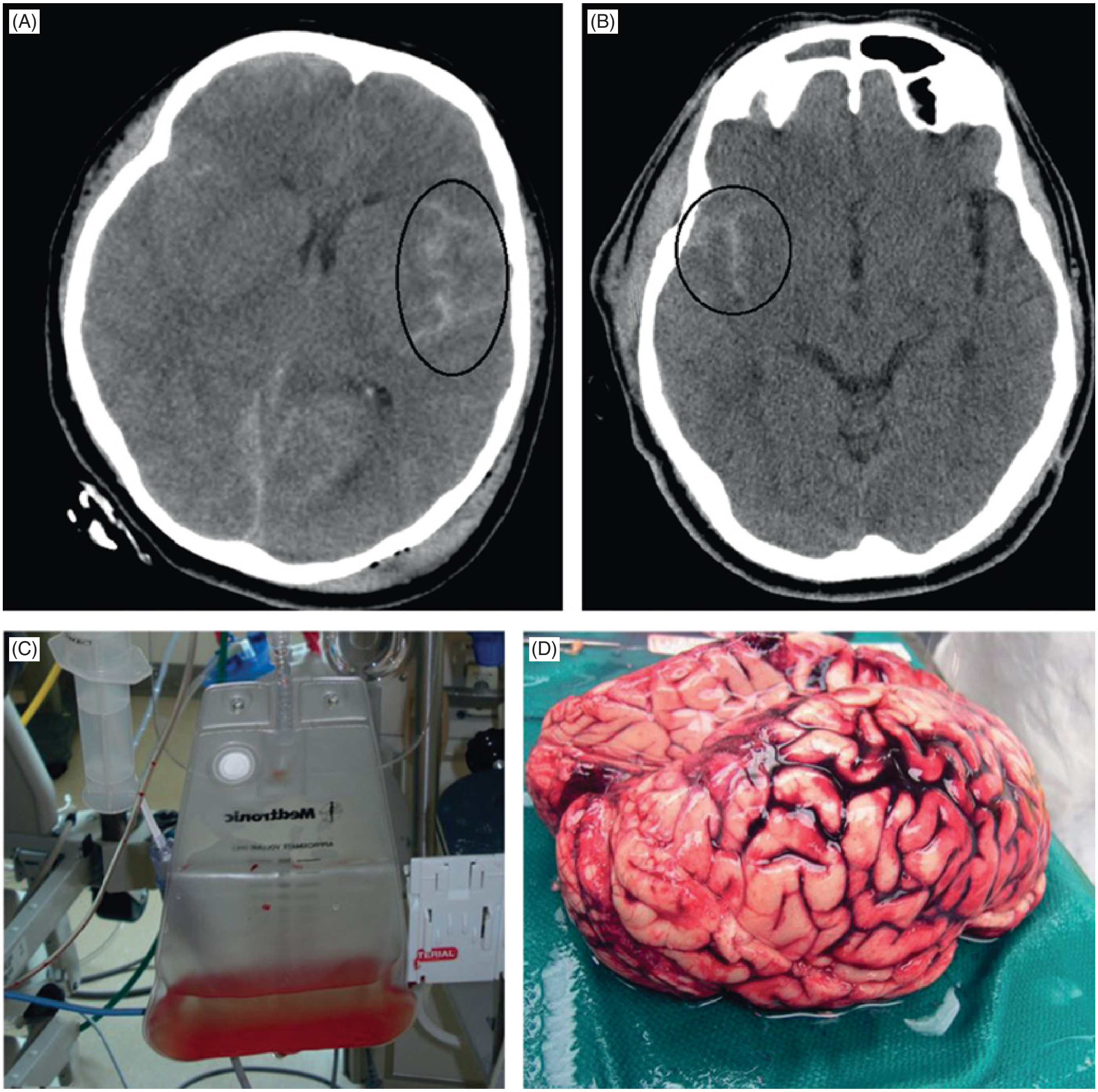

Figure 1.20 A–D CT scan of SAH shows the fingerlike projections of hyperdense blood as it tracks along the sulci (circle; A). CT scan showing left SAH (circle; B). Bloody CSF drainage from a ventriculostomy catheter in a patient with SAH (C). Autopsy specimen of a brain with SAH seen here tracking along the sulci of the brain beneath the arachnoid membrane (D). Image courtesy of Dr. Matthew Miller, LA County Coroner Office.

The treatment of traumatic SAH is conservative, with serial CT scan evaluation at the early stages. During the acute phase, intense vasospasm caused by subarachnoid blood may worsen symptoms and outcome by causing ischemia in the adjacent normal brain. Intracranial vasospasm can be monitored using transcranial doppler and treated with calcium channel blockers in severe SAH. Long-term sequelae include obstructive hydrocephalus, which may require a ventriculoperitoneal shunt for decompression. CT scan evaluation should be performed to rule out hydrocephalus in patients presenting with delayed deterioration of symptoms.

Intraventricular Hemorrhage

Hemorrhage into the ventricular system is more commonly due to hypertension than to trauma. Sometimes blood from a traumatic lesion (i.e., SAH) will track into the ventricular system, or lacerations of the brain parenchyma may communicate directly with the ventricles. Complications include obstructive hydrocephalus, which may require placement of a ventriculoperitoneal shunt (Figure 1.21 A,B).

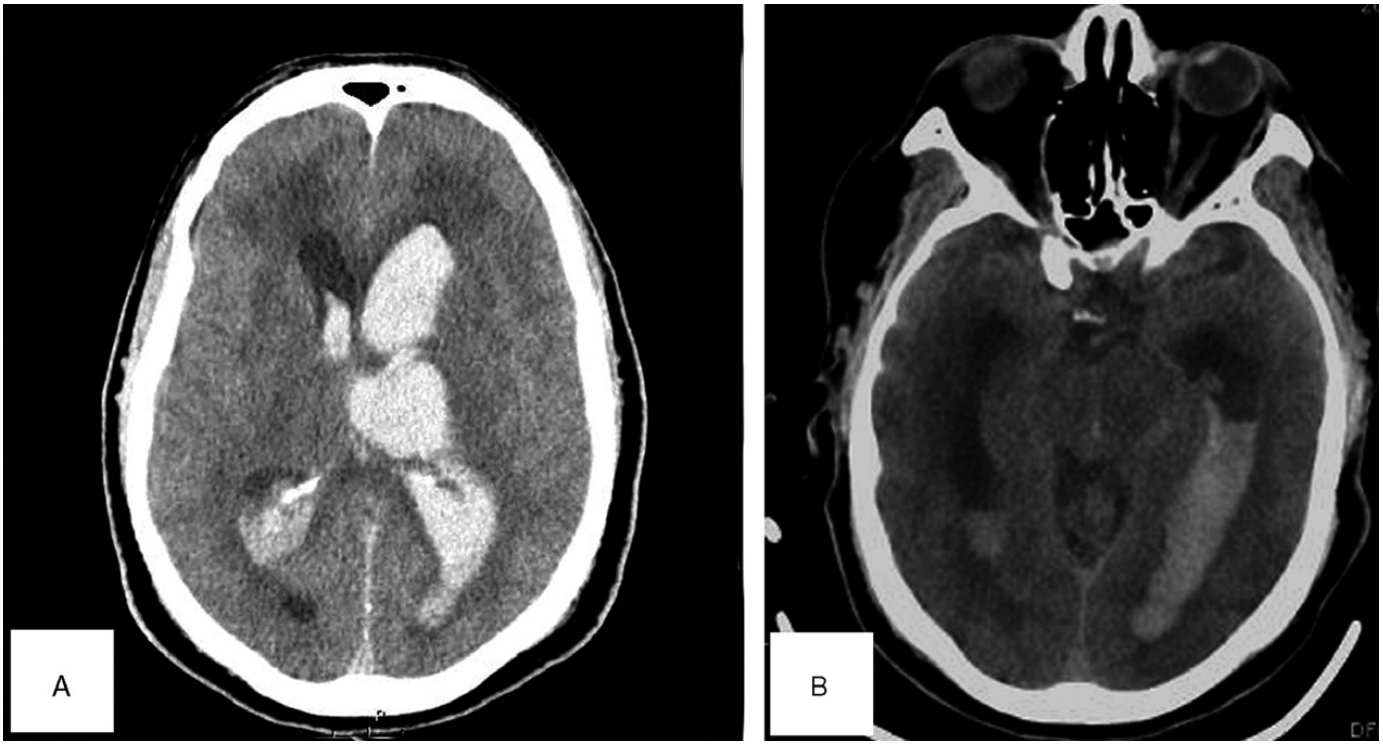

Figure 1.21 A,B CT scans show massive bilateral intraventricular hemorrhage.

Intraparenchymal Hemorrhage

Intraparenchymal hemorrhage is confined to the brain parenchyma and bleeding in these cases is usually tamponaded by surrounding tissue. They are commonly caused by penetrating injuries or bone fragments. Edema surrounding the area of hemorrhage can result in significant swelling or midline shift, and these injuries are especially susceptible to secondary brain injury (Figure 1.22 A–C).

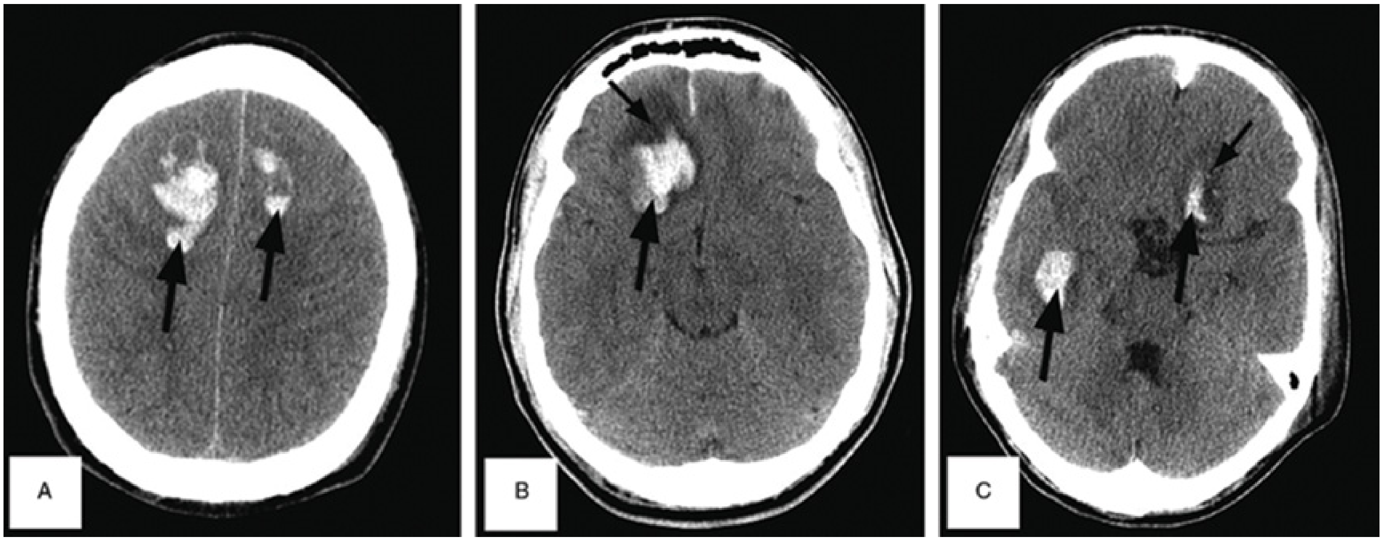

Figure 1.22 A–C CT scan revealing large bilateral intraparenchymal hemorrhages (A). CT scan of a patient with a large right intraparenchymal hemorrhage (large arrow) with surrounding ischemic brain tissue (small arrow; B). CT scan with two intraparenchymal hemorrhages in the right temporal and left frontal areas (large arrows); the frontal hemorrhage is surrounded by edematous brain tissue (small arrow; C).

Cerebral Contusion

Cerebral contusion occurs as the brain parenchyma strikes fixed portions of the skull during sudden deceleration or acceleration. It is often associated with a coup–contrecoup injury and may be found relatively distant from the site of head impact. Locations most commonly prone to contusion include the frontal lobe striking the anterior skull and the temporal lobe striking the projections of the sphenoid bone (Figure 1.23 A–C).

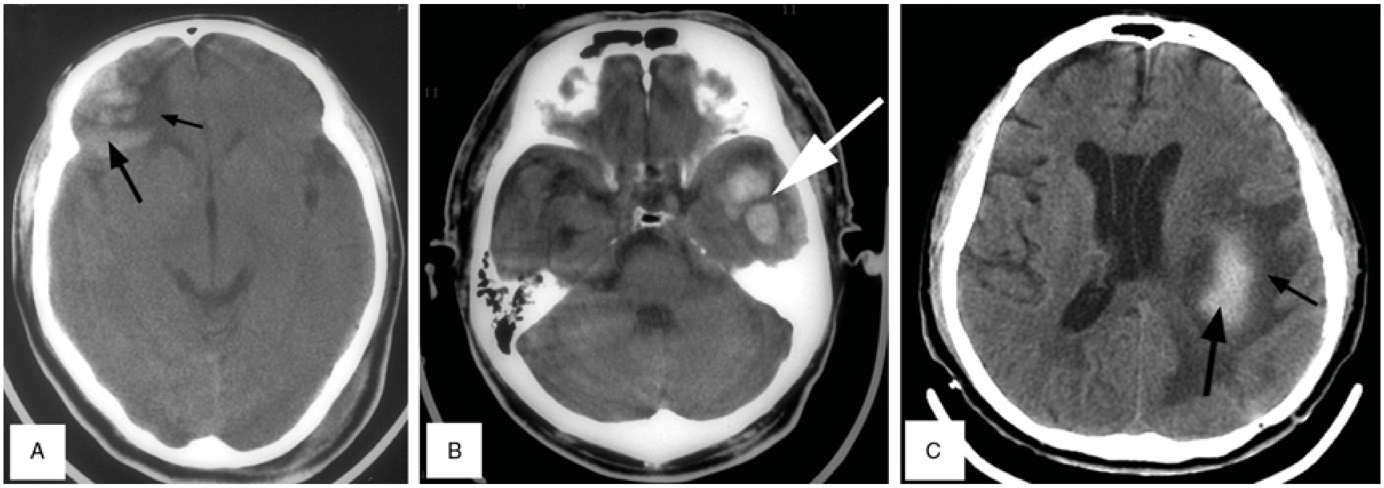

Figure 1.23 A–C CT right frontal lobe contusion (large arrow) with surrounding edema (small arrow; A). Axial CT scan showing a left temporal lobe contusion (arrow) with surrounding edema (B). Axial CT scan with large left-hemispheric contusion (large arrow) and surrounding edema (small arrow; C).

The clinical presentation depends on the size and location of the contusion. Frontal lobe contusions are characterized by agitation, confusion, repetitive questioning, impaired short-term memory, and aggressiveness, which often requires physical or chemical restraint. Initially, the contusion is primarily hemorrhagic. Over a period of hours to days, localized cerebral edema may develop, causing an increased mass effect.

Cerebral contusions, especially frontal or temporal, are also characterized by a high incidence of posttraumatic seizures. Because of this, routine prophylactic treatment with anticonvulsants is recommended for approximately seven days following injury.

Penetrating Head Injury

The vast majority of penetrating head injuries are the result of gunshot wounds. These are devastating injuries that often result in death or profound disability in survivors. As a bullet enters the skull, it produces multiple fragments (both from the shattered skull and from bullet fragmentation) that cause multiple injuries. Although the skull absorbs some kinetic energy, a high-velocity bullet retains sufficient energy to cause a transient cavitation once it enters the brain parenchyma. This produces a rapidly expanding cavity and subsequent recoil, resulting in further damage of the brain tissue (Figure 1.24 A,B, Figure 1.25 A,B, Figure 1.26 A,B, Figure 1.27 A,B).

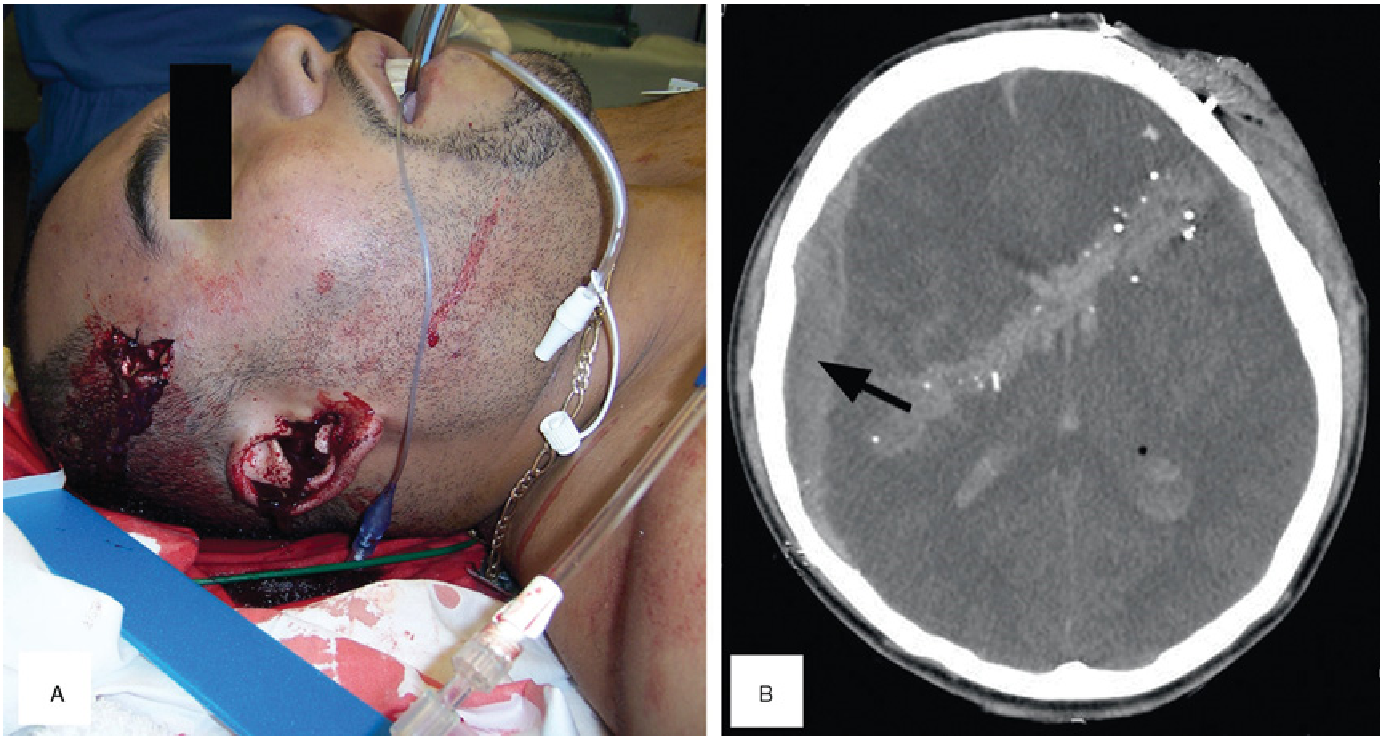
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Figure 1.24 A,B Gunshot wounds to the brain. Fatal gunshot wound to the right frontotemporal area (A). CT scan showing a nonsurvivable transaxial bullet tract, a right acute SDH (arrow), blood in the ventricles, and metallic fragments (B).

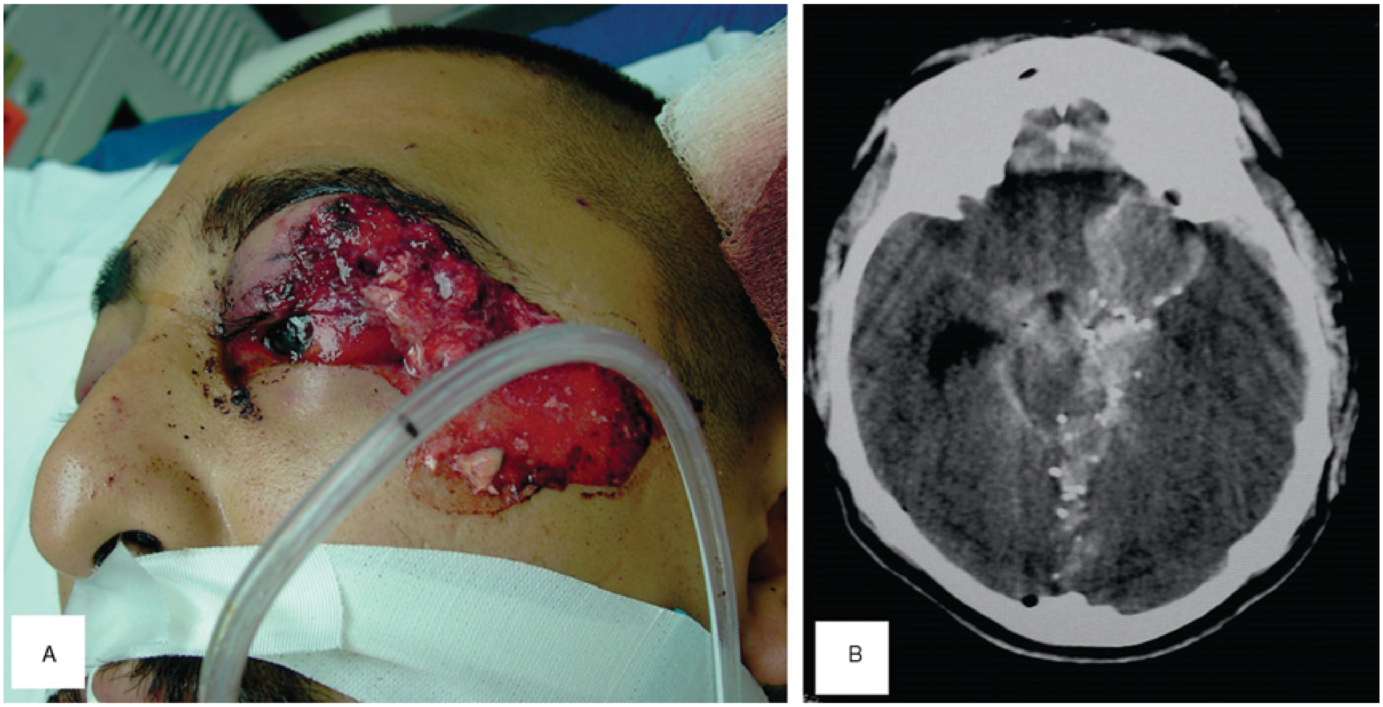

Figure 1.25 A,B Gunshot wound to the brain. Patient with a fatal gunshot wound with entry in the left orbit (A). CT scan showing a massive nonsurvivable brain injury. The patient became an organ donor (B).

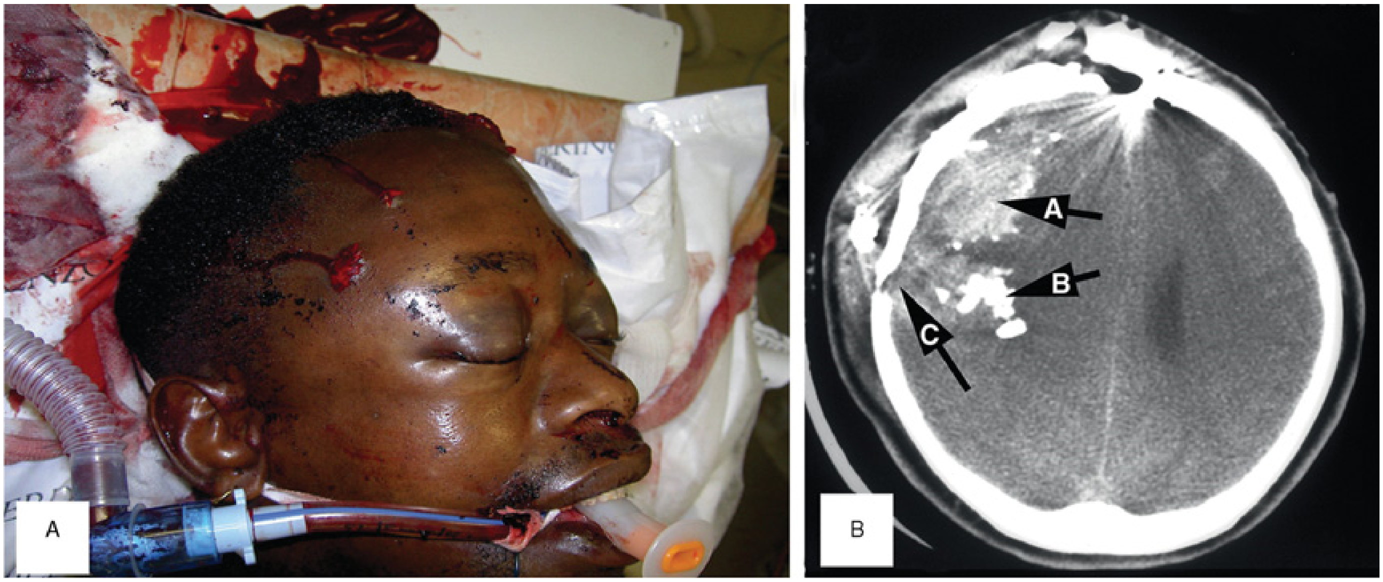

Figure 1.26 A,B Gunshot wound to the brain. Patient with multiple gunshot wounds to the head. Note the cephalohematoma and periorbital ecchymosis (A). CT scan showing intraparenchymal hemorrhage (arrow A) and intraparenchymal bullet fragments (arrow B), and an open frontotemporal skull fracture (arrow C; B).

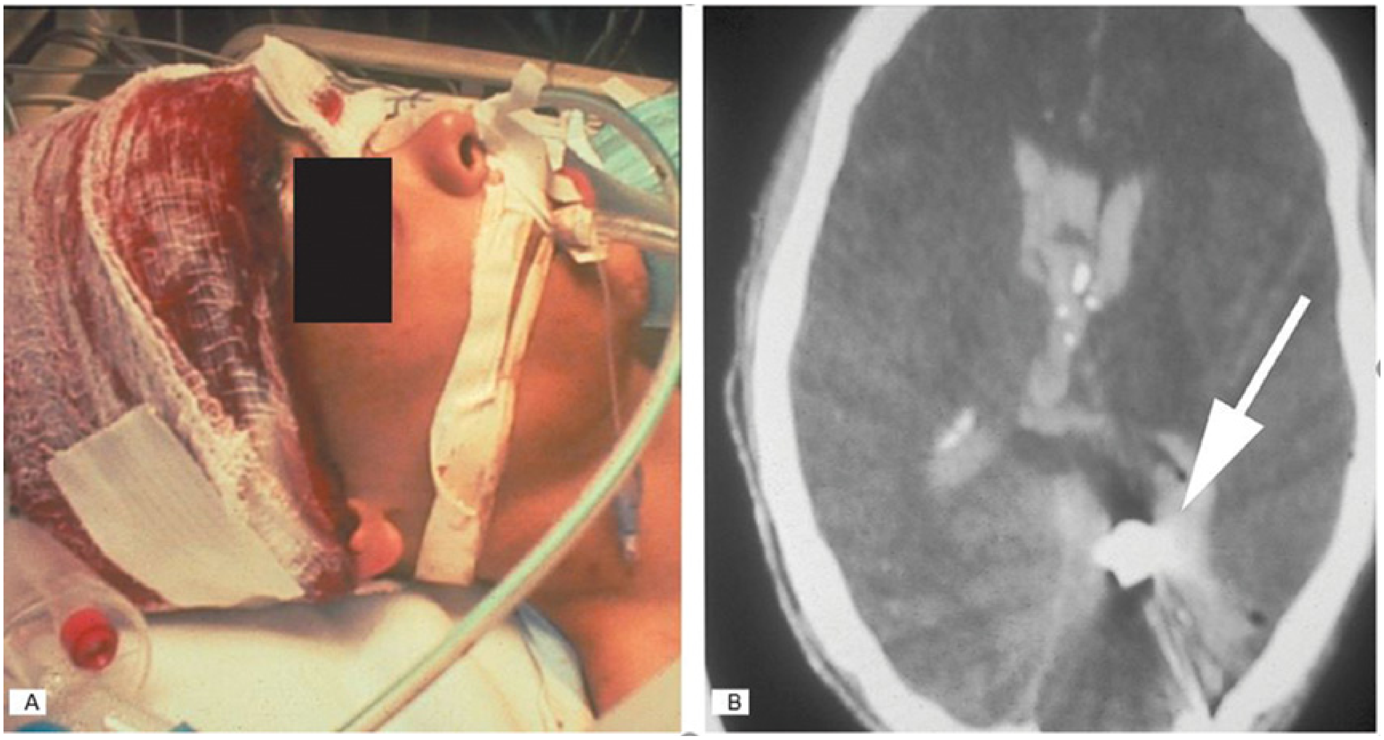

Figure 1.27 A,B Gunshot wound to the brain. Pediatric victim with a fatal gunshot wound to the head (A). The CT scan shows intraventricular and intracerebral hemorrhages and a bullet in the occipital area (arrow; B).

Other types of penetrating injuries involve less kinetic energy and have a better prognosis. Long-distance shotgun injuries, stab wounds, impalement injuries, and low-velocity shrapnel wounds can produce all of the same injuries, but most commonly result in open skull fracture and direct laceration of brain parenchyma (Figure 1.28 A,B, Figure 1.29 A,B, Figure 1.30 A,B).

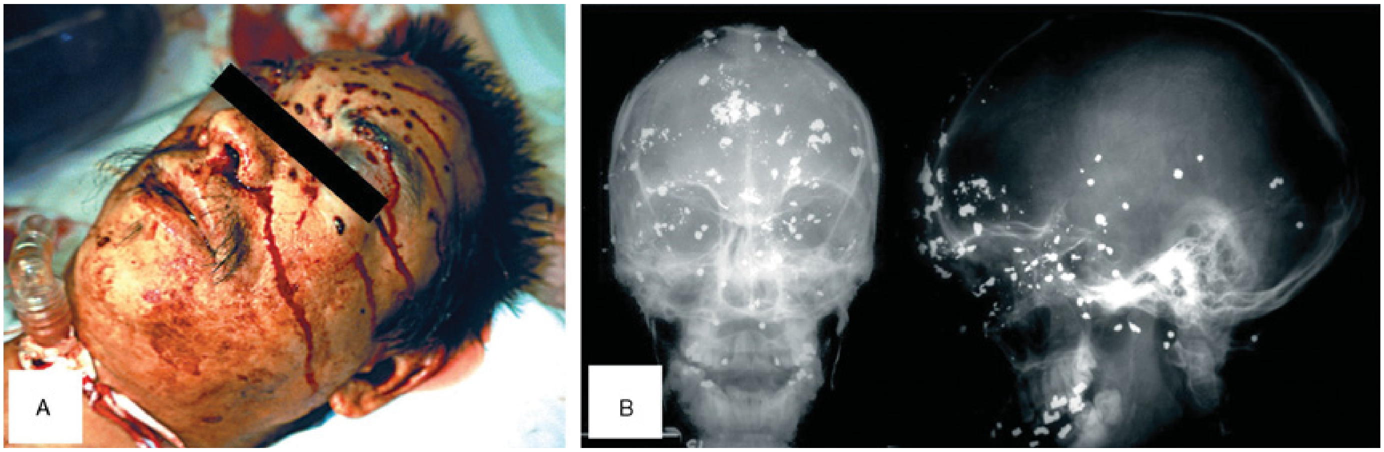

Figure 1.28 A,B Shotgun wounds to the brain. Victim of a fatal shotgun injury to the head, with multiple pellet wounds to the face and head (A). Radiographs in the same patient showing multiple shotgun pellets of the face and skull (B).

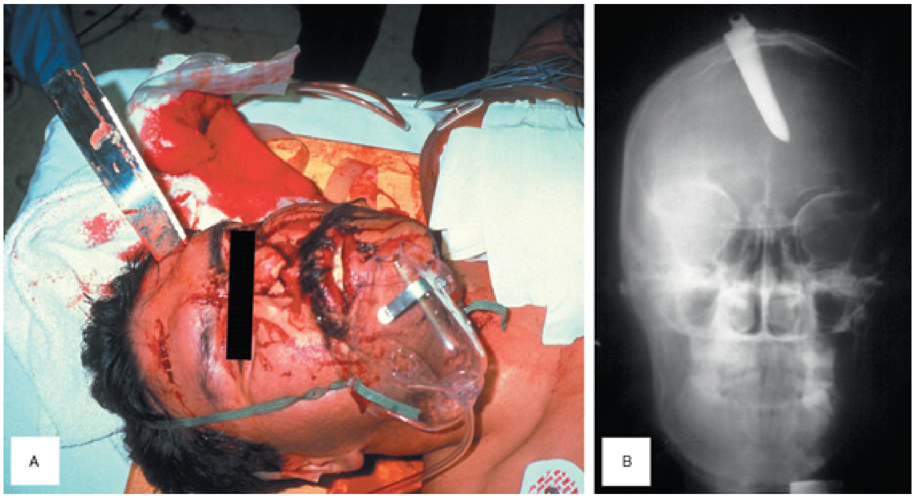

Figure 1.29 A,B Knife injuries to the head. Foreign bodies should be removed only after an angiogram or in the operating room. Stab wound to the head with an embedded knife in the frontal area. The patient was awake and alert (A). Anteroposterior radiograph revealing the knife blade within the cranium. The knife was pulled out in the operating room, after angiography, without any complication (B).

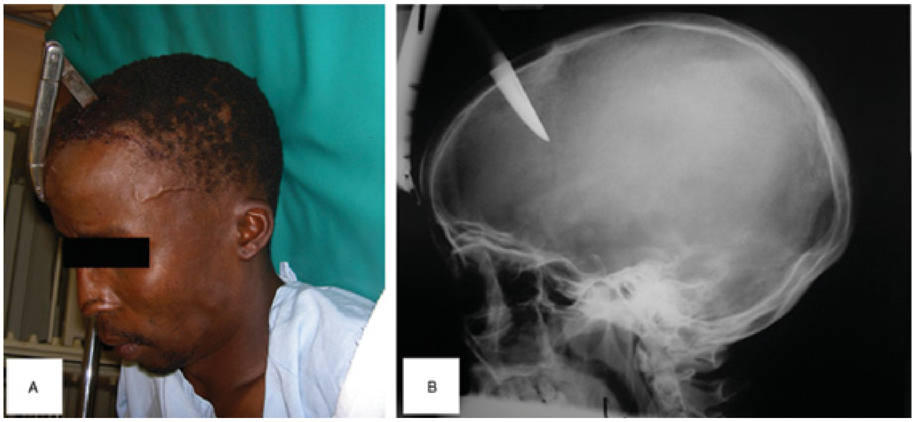

Figure 1.30 A,B Knife injury to the head. Stab wound to the head with a switchblade impaled in the cranium. The patient is awake and alert (A). Lateral skull radiograph revealing the knife penetrating the skull and impaled in the brain parenchyma. The knife was pulled out in the operating room, after angiography, without any complication (B).

A careful physical examination is indicated with stab wounds of the scalp to ensure that the knife blade has not broken off inside the cranium. Wounds associated with these injuries may appear innocuous and may be missed altogether if covered with matted hair. Many of these patients are relatively asymptomatic and often have a normal neurologic examination in spite of a dramatic injury. Plain anteroposterior and lateral radiographs of the skull will accurately delineate the location and depth of penetration of radiopaque objects. If the patient can fit into the CT scan gantry without disturbing the impaled object, the CT scan will demonstrate underlying brain injury, although metal artifact may be problematic. Impaled foreign bodies should be removed only after an angiogram to rule out a vascular injury or in the operating room, where prompt vascular control can be obtained once the object is removed. Surgical debridement and control of cerebral hemorrhage should be performed without any delay.

Management depends on the overall condition of the patient. Frequently, gunshot wound victims have multiple wounds of the chest, neck, or abdomen that may take priority in terms of restoring hemodynamic stability to the patient. Bleeding from a gunshot wound of the head may be profuse, but hemorrhagic shock is uncommon with isolated head injuries, and associated injuries should be sought to explain the hemodynamic compromise.

Patients with penetrating head injury have a high rate of complication. The incidence of posttraumatic seizure is more than 50%, and seizure prophylaxis should be administered for at least seven days. Gunshot wounds to the brain are associated with a high incidence of coagulopathy (massive release of tissue thromboplastin from the injured brain), diabetes insipidus, labile hemodynamics, arrhythmias, hyperglycemia, and neurogenic pulmonary edema. Although the prognosis after gunshot wounds to the brain is poor and the mortality is higher than 90%, these patients should be treated aggressively to obtain maximal outcome.

Brain Herniation

Herniation is the result of a pressure gradient between the intracranial compartments and can take place in different areas of the cranial cavity.

Transtentorial herniation is the most common type of brain herniation. It may cause compression of the third cranial nerve (resulting in a dilated pupil), the upper brain stem, and the cerebral peduncles. Sometimes there is compression of the basilar artery and the posterior cerebral arteries, which results in severe ischemia of the occipital lobe (Figure 1.31, Figure 1.32 A,B).

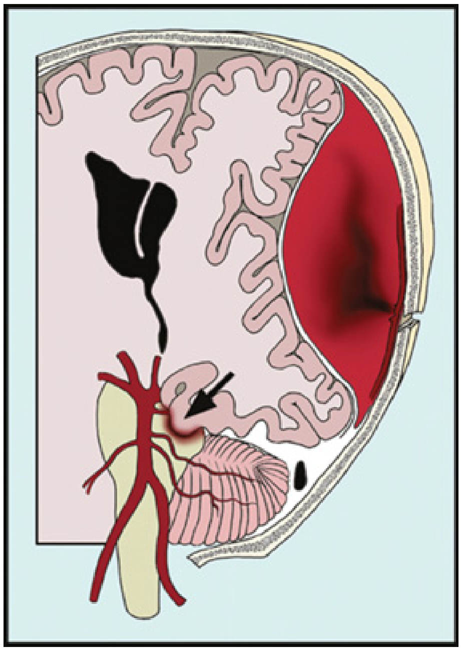

Figure 1.31 Brain stem herniation. Illustration of an EDH with acute mass effect and compression of the ipsilateral cerebral peduncle resulting in uncal herniation and compression of the brain stem (arrow).

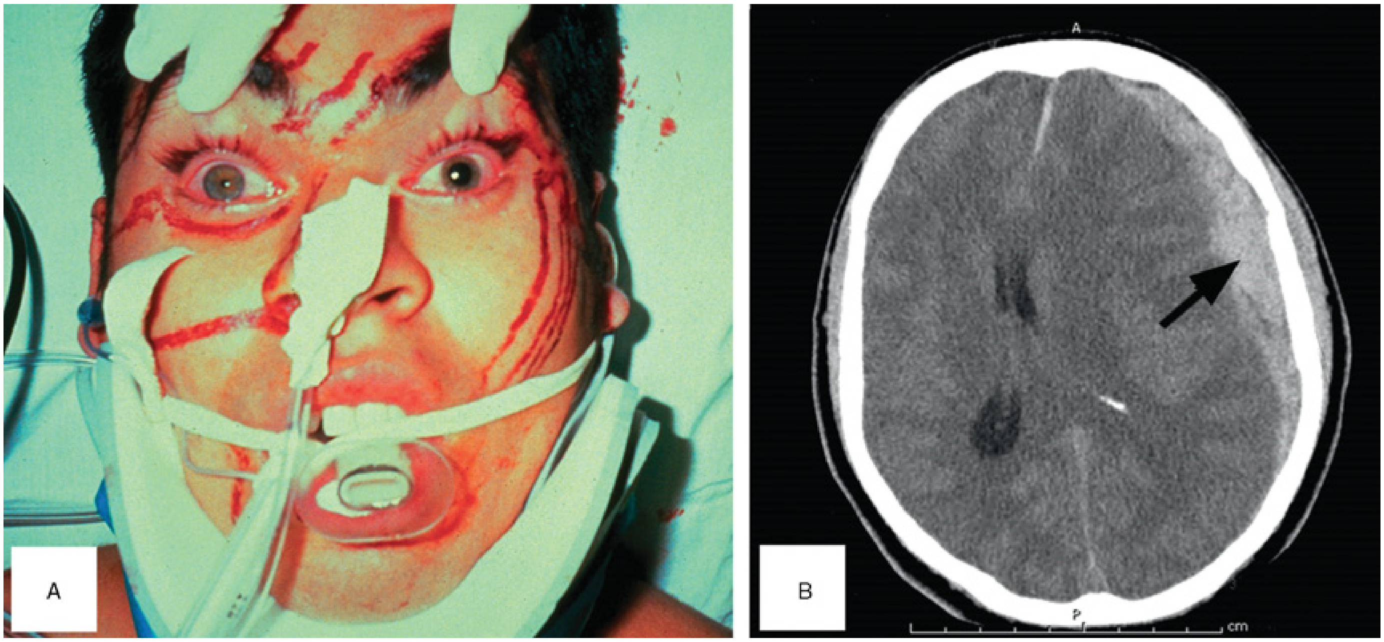

Figure 1.32 A,B Brain stem herniation. Patient with transtentorial herniation from blunt head trauma. The left pupil is fixed and dilated (A). CT scan shows a large left SDH (arrow) with midline shift. This compression resulted in brain stem herniation (B).

Falcine herniation occurs due to hematoma or swelling in one cerebral hemisphere, resulting in herniation of the hemisphere across the midline, under the falx, and downward across the tentorium, causing compression of the midbrain. Compression of the anterior cerebral artery can cause ischemic damage to the frontal and parietal lobes.

Foramen magnum herniation occurs when parts of the cerebellum herniate into the foramen magnum, compressing the medulla and the upper cervical spinal cord. Brain herniation with compression of the brain stem is a catastrophic and usually lethal complication. The patient develops severe deterioration of the level of consciousness with a GCS 3–5, ipsilateral or bilateral pupil dilation, decorticate or decerebrate posturing, irregular breathing, bradycardia, and hypertension.

In the early stages of herniation, emergency craniectomy and decompression can be life-saving. Temporizing measures to reduce the intracranial pressure and improve CPP, include moderate hyperventilation to a pCO2 of 32–35 mmHg, osmotic and loop diuretics, sedation, and paralysis.

Diffuse Cerebral Edema

Diffuse cerebral edema may be associated with mass lesions or may occur in isolation. It is more common in children and infants than in adults. Cerebral contusions are prone to develop severe focal edema in the surrounding tissues. The edema involves the glial cells, myelin sheaths, and intercellular spaces. It may cause increased intracranial pressure, which may impair brain circulation or, in severe cases, result in brain herniation. Treatment is directed at decreasing brain water content with cautious fluid administration, osmotic and loop diuretics, and correcting any hypotension or hypoxia, which may cause secondary brain damage and worsen the edema. Hypertonic saline (3% NaCl, 250 mL) may also be considered to improve cerebral perfusion pressure and reduce cerebral edema in hemodynamically unstable patients. Other interventions include barbiturate coma and decompressive craniectomy in refractory cases, where the typical less-invasive measures fail to control severe intracranial hypertension (Figure 1.33 A,B, Figure 1.34 A–E).

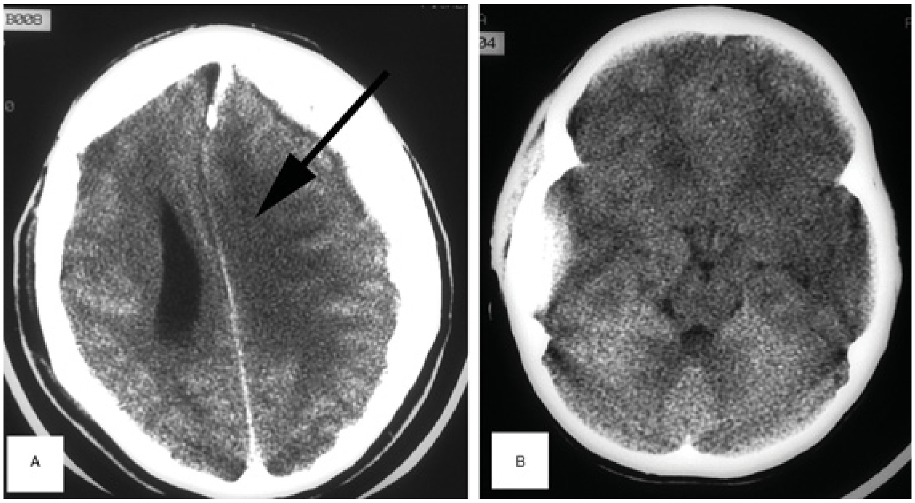

Figure 1.33 A,B Diffuse cerebral edema. CT scan showing severe edema of the left hemisphere (arrow) with obliteration of the left ventricle and midline shift (A). CT scan with diffuse brain edema and obliteration of both ventricles (B).

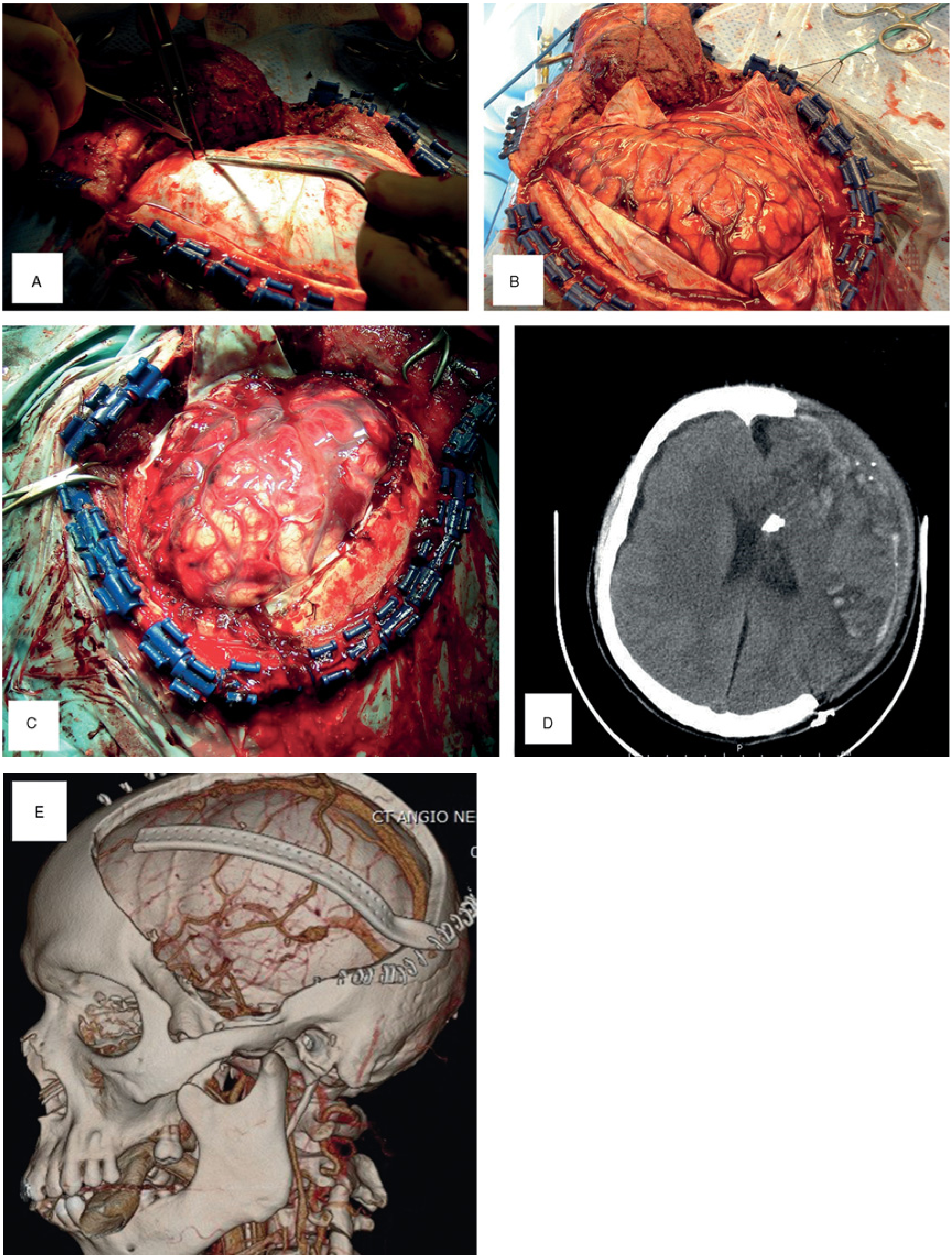

Figure 1.34 A–E Diffuse cerebral edema. Intraoperative photograph after removal of the skull shows tense and bulging dura due to massive brain edema (A). Edematous brain bulging from the cranium after release of the dura with engorged cerebral vasculature (B). Brain material bulging beyond the cranial vault with herniation through the craniectomy site (C). CT scan of the same patient with herniation of the brain beyond the edges of the craniectomy site (D). Decompressive craniectomy for severe intractable brain edema (E).

Diffuse Axonal Injury

Diffuse axonal injury results from disruption of neurons at the interface of gray matter and white matter in the brain due to sudden deceleration or acceleration injuries of the head. Gray matter has greater mass than white matter because of higher water content and, as a result of greater momentum during sudden deceleration, continues farther than white matter, producing shear forces at the gray–white interface. Initial diagnosis is difficult, given that many other causes of coma must also be considered, including intoxication, encephalopathy, hypoglycemia, hypovolemic shock, and brain stem injury. It is difficult to prognosticate early in patients with diffuse axonal injury, as patients with less extensive injury may regain consciousness fairly rapidly (within 24 hours), while others continue in a persistent vegetative state. In rare cases, patients with this injury may awaken after months of coma.

The CT scan in patients with diffuse axonal injury is often misleadingly normal or near normal. Findings may include petechial hemorrhages, seen mainly in the central part of the brain (corpus callosum, basal ganglia, and other medial structures), although MRI is more sensitive in delineating the extent of axonal disruption (Figure 1.35 A,B).

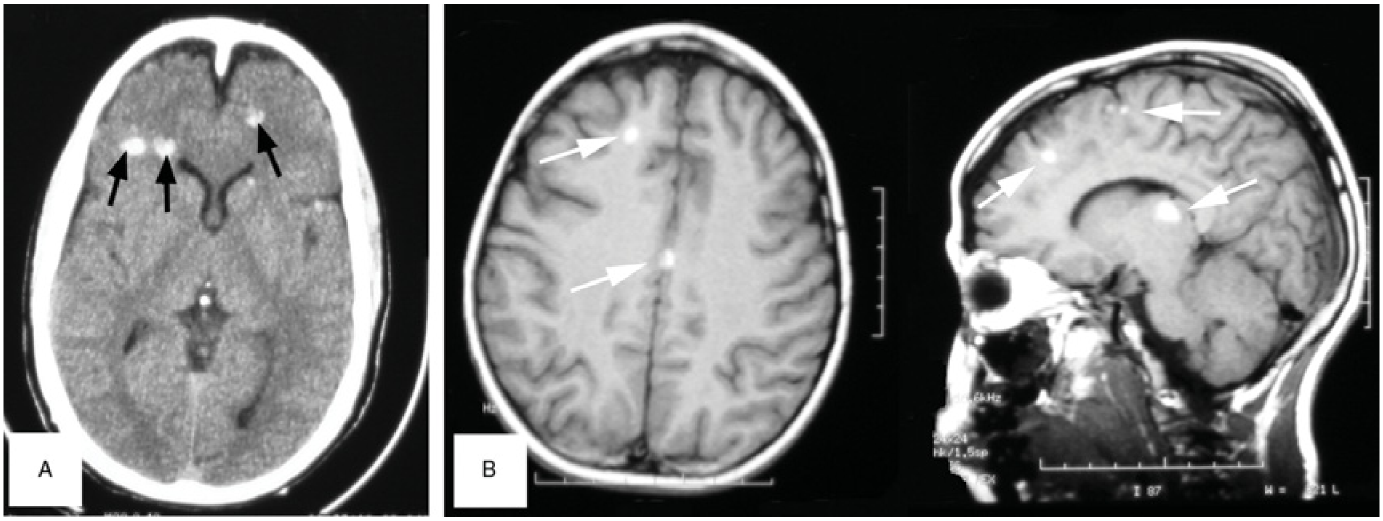

Figure 1.35 A,B Diffuse axonal injury. CT showing focal petechial hemorrhages in the frontal lobes at the gray–white matter junction (arrows) in a patient with diffuse axonal injury (A). MRI showing multiple high-intensity focal hemorrhages (arrows), including those at the gray–white matter interface (B).

Pediatric Head Injury

Anatomically, the child's skull is more compliant than that of adults because it is less calcified and has unfused sutures. Because of this greater compliance, more kinetic energy can be transmitted directly to the brain during trauma and cerebral contusion is a common injury. Because of the loose adherence of the dura to the inner table of the skull, EDHs are more common in young children. Children also more frequently develop diffuse cerebral hyperemia or diffuse edema as their principal injury pattern. Because of this propensity for diffuse hyperemia, mannitol is used with caution in young children with evidence of elevated ICP following head trauma. Mannitol causes a transient increase in cerebral perfusion and expands the vascular compartment temporarily before exerting its diuretic effect. Some authors recommend using loop diuretics and mild hyperventilation, rather than mannitol, when managing elevated ICP in a young child (Figure 1.36 A–C).

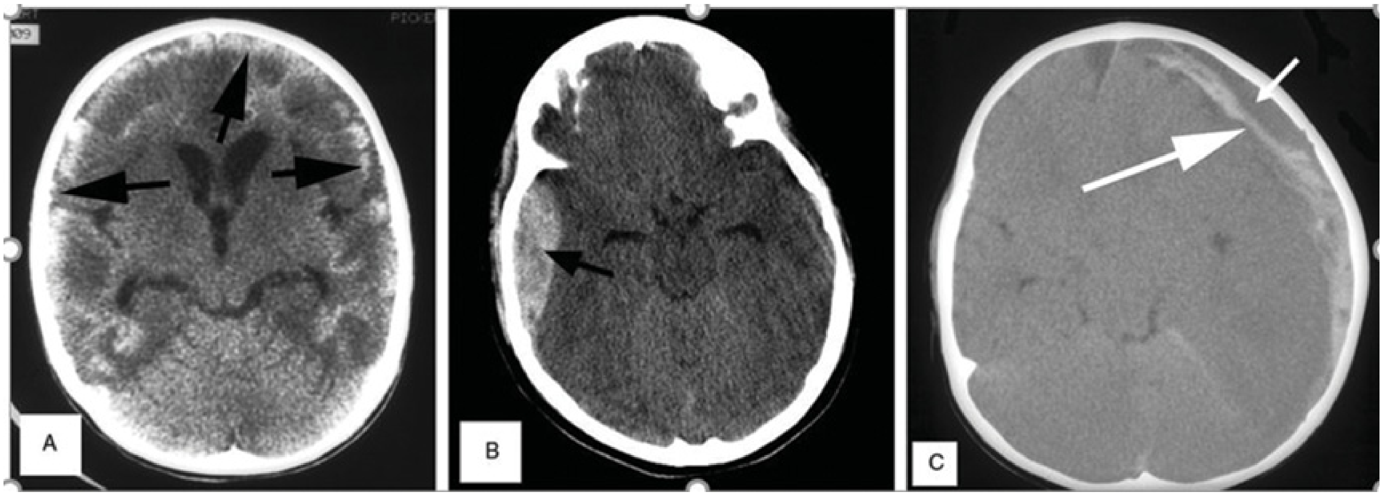

Figure 1.36 A–C Pediatric head injuries. CT scan of a child with shaken baby syndrome showing dilated ventricles and multiple cortical calcifications (arrows), suggestive of multiple previous SDHs (A). EDH (arrow) in a 10-year-old patient (B). CT scan of the head of a child with shaken baby syndrome, showing a chronic SDH (hypodense area, small arrow) with acute rebleeding (hyperdense area, large arrow) on the left (arrow), as well as diffuse cerebral edema and compressed ventricles (C).

Children also manifest cerebral concussion differently than adults. The "infant concussion syndrome" consists of the transient appearance of pallor, diaphoresis, vomiting, tachycardia, somnolence, and weakness, often occurring in an infant after relatively minor head trauma (e.g., falling off a changing table). CT scan is invariably normal, and the child often will make an equally dramatic recovery while still in the emergency department. Separation of cranial sutures, a bulging fontanelle, or increasing head circumference may be the initial clues to head injury in infants, but CT scan is generally used to make the diagnosis of serious head injury in children. Absolute indications for CT of the head in pediatric patients should include GCS <15, history of loss of consciousness, amnesia, seizures, headache, suspected CSF leak from the nose or ear, raccoon eyes, and Battle's sign. If the only sign or symptom is a scalp hematoma, the child should undergo either a CT scan or observation in the emergency department for about six hours.

The principal concern in evaluating children with head trauma is to consider the possibility of nonaccidental trauma. A history incompatible with the severity of injury or that involves activities that the child would be developmentally incapable of performing can be an initial clue that the injuries may be due to abuse.

Tips and Pitfalls

- Closed head injuries alone do NOT produce hypotension, except in terminal stages. Look for blood loss or associated cervical spinal cord injury.
- Scalp lacerations may bleed a lot! Suture the wound and apply a compression dressing early.
- Minor head injuries (GCS 13–15) may be associated with significant intracranial lesions, especially in elderly patients.
- Young pediatric trauma patients with a scalp hematoma should undergo CT scan or a period of observation prior to discharge to rule out EDH, even in the setting of a normal GCS, no history of loss of consciousness, and no other symptoms or signs.
- Do not give seizure prophylaxis for longer than seven days. Prolonged prophylaxis does not reduce the risk of late seizures.
- Coagulopathy and diabetes insipidus are common in severe brain trauma. Monitor closely and start treatment early.
- Do not insert a nasogastric tube in the setting of a basilar skull fracture in the anterior cranial fossa, as the tube may inadvertently travel into the parenchyma!

Chapter

2

Facial Injury

David Beversluis, Tamara Chambers, and Edward J. Newton

Introduction

Facial injuries are common and can involve both soft tissue injury and bony injury. These often occur because of motor vehicle collisions, secondary to direct impact against the windshield, steering wheel, or dashboard, as well as from broken glass fragments, causing lacerations and eye injuries. Many facial injuries also occur because of physical assault or because of falls to the head and face, especially in the elderly, who are less able to protect their face while falling.

Clinical Examination

The face contains many sensitive structures intimately involved in the human senses of sight, smell, hearing, and taste, all of which are vital for human communication. After completion of the primary survey, it is important to examine each systematically to detect and manage localized injuries.

Overall Face – The face should be palpated for areas of localized tenderness, swelling, malformation, crepitus, and abnormal motion, all of which can indicate the presence of underlying fractures. All lacerations should be identified and direct pressure applied while the exam continues. The teeth, maxilla, and mandible should be palpated and pulled forward slightly to reveal a possible LeFort fracture. The face should be examined for asymmetry, which can be due to direct trauma and also secondary to facial nerve injury.

Eyes – The orbit and periorbit should be examined as part of the secondary survey. The exam should include assessment of the following important elements: (1) external examination, (2) extraocular motility, (3) confrontation of visual fields, (4) visual acuity, (5) pupil examination, (6) intraocular pressure, (7) slit lamp exam, and (8) fundoscopic exam.

Various elements of a full ocular exam may be challenging to obtain in the acute trauma setting and may be deferred to specialist consultation. Visual acuity, for example, may be difficult to obtain formally; however, a rough estimate can be made by having the patient count fingers or report light perception. External visual exam should assess for evidence of soft tissue swelling, foreign body, or laceration. The pupils should be checked for symmetry and equality of pupillary reflex. Findings such as a peaked pupil can raise suspicion for globe rupture. The position of the globe should be noted with concern for enophthalmos (indicates blowout fracture) or exophthalmos (indicates increased retroorbital pressure from hematoma). If the patient is stable, a slit lamp exam can be performed to look for evidence of corneal foreign bodies, lacerations, or abrasions, as well as to visualize the anterior chamber for a hyphema.

Ears – Both the external ear and external auditory canal should be inspected during the secondary survey. Lacerations, avulsions, or hematomas in the cartilaginous portions or soft tissues of the external ear must be noted. The auditory canal should be examined with an otoscope for bleeding or CSF otorrhea (concerning for ruptured tympanic membrane and/or basilar skull fractures). The tympanic membranes must be examined for hemotympanum, which represents accumulation of blood in the middle ear and is associated with an increased risk of intracranial injury or fracture.

Nose – The nose is inspected for skin or cartilage lacerations, as well as for nasal bone fractures, often causing deformity and localized tenderness at the nasal bridge. The nares should be inspected with an otoscope for the presence of epistaxis or CSF leak, as well as nasal septal hematoma.

Mouth – The mouth should be examined for lacerations, teeth avulsions or fractures, swelling of the tongue, and oral mucosa. Occlusion should also be noted, which would suggest an isolated mandible or more complex facial fracture. This is accompanied by an evaluation of the patient's airway, which will have a direct impact on the clinician's decision to intubate the patient.

Investigations

The provider must use clinical judgment in assessing the need for diagnostic imaging for facial injuries. Not all patients require imaging; however, if there is any concern for a facial fracture due to localized tenderness, asymmetry, or other concerning signs, the imaging modality of choice is the maxillofacial CT. Given the ubiquity and superiority of CT scans, plain radiographs are now rarely indicated for facial trauma. However, if available, panorex X-ray views remain useful for identifying suspected mandible fractures.

There are several non-radiographic tests that are useful for facial injuries, depending on the specific injury and the practice location. Specialists, such as ophthalmologists, may be called upon to carry out many of these tests, but they can also often be performed in an emergency department. Retinal detachment and other intraocular injuries (anterior chamber hyphema, corneal abrasions) should be examined with careful fundoscopy and slit lamp exam. Tonometry can be used to assess for posttraumatic glaucoma or retroorbital hematoma; however, this test should never be done if there is concern for ruptured globe. Lacrimal duct laceration can be assessed with fine probes by an ophthalmologist, whereas parotid duct laceration is often demonstrated with a sialogram performed by a surgeon.

General Management

The lower face and neck contain structures that define and maintain the integrity of the airway. Consequently, facial injuries at times assume the highest priority in trauma management until airway patency and adequate ventilation can be established. Because facial tissues are highly vascularized, severe bleeding into the oral cavity can occlude the airway, especially when patients are obtunded from head injury or intoxication. In the presence of massive bleeding, airway compromise may be produced by placing the patient supine for spinal immobilization. Blood, secretions, fragments of teeth, and foreign bodies must be directly removed or suctioned to avoid aspiration and airway occlusion. Intubation is often indicated for facial injuries in order to protect the patient's ability to ventilate. With severe trauma, normal oropharyngeal landmarks may be severely distorted and alternative approaches, including awake, fiberoptic oral- or naso-tracheal intubation, should be considered. Nasotracheal intubation should not be attempted in patients with concern for nasal, basilar skull, or Le Fort fractures. The decision regarding the method of intubation should be based on the urgency of protecting the patient's airway, experience of the physician, and the facilities and resources of the emergency room. Finally, in all cases, the physician should be immediately available to perform a cricothyroidotomy if conventional intubation fails. Prolonged and repeated attempts at intubation are detrimental to the patient, and early use of cricothyroidotomy is essential and often life-saving.

As facial injuries are often dramatic, they can easily distract the inexperienced clinician from more critical tasks. If the airway is not threatened, most facial injuries can be safely deferred until additional systemic life-threatening problems have been addressed. Active bleeding (such as scalp wounds) should be timely addressed, as these injuries can typically be controlled with local measures, and ongoing blood loss can lead to hemorrhagic shock. Treatment of facial fractures can be deferred until the patient is hemodynamically stable.

Minor eye injuries (e.g., corneal abrasion, rust ring, eyelid laceration) can be deferred, but sight-threatening injuries should be dealt with immediately and consultation with an ophthalmologist is essential. Once the possibility of a ruptured globe has been established, the eye should be protected by use of a Fox shield or similar device to prevent further pressure on the globe. Retroorbital accumulation of blood or air, often due to direct facial and eye trauma, associated with deteriorating vision, massive elevation of intraocular pressure, or exophthalmos, requires emergent decompression by lateral canthotomy with cantholysis. Entrapment of extraocular muscles by fractures, indicated by loss of extraocular movements, or seen on facial/orbit CT, should be relieved urgently. All of the aforementioned factors should prompt emergent consultation to an ophthalmologist.

Penetrating trauma of the ear is relatively uncommon and is managed by minimal debridement, irrigation, and primary closure. Blunt trauma is more common and often results in perichondrial hematoma formation in the ear pinna or cartilage. As ear cartilage is dependent on its perichondrium covering for blood supply, an interposed hematoma can result in ischemic necrosis of the cartilage, resulting in a "cauliflower ear" deformity. Consequently, the ear must be examined for this condition, and a hematoma should be drained or aspirated. A pressure dressing is applied to prevent reaccumulation of the hematoma or abscess formation.

Superficial facial lacerations can typically be managed at the bedside and should be repaired carefully to maximize cosmetic outcome. Debridement of wound margins should be minimized, cartilaginous structures should be preserved, and fine sutures with minimal inflammatory properties should be used in closing the wounds. Complex lacerations involving delicate and essential facial structures such as the eyelid should be referred to a specialist. Intraoral lacerations are repaired with absorbable sutures. Antibiotics are unnecessary for most facial lacerations, although open fractures require prophylactic coverage.

Tips and Pitfalls

- Severe oromaxillofacial trauma can produce delayed airway occlusion from swelling or bleeding. These patients should be intubated early or observed carefully in a monitored environment.
- Any attempts to perform endotracheal intubation in the presence of extensive facial trauma should be accompanied by preparation for cricothyroidotomy in the event that oral intubation fails.
- Always account for missing teeth. The missing teeth might be in the tracheobronchial tree, resulting in airway obstruction and even a lung abscess.
- Blind clamping of bleeding sites is rarely successful, and it can injure nerves and other structures that run in proximity to vessels.
- Injury to the cranial nerves is difficult to detect in severely injured patients, especially if they are comatose, intoxicated, or otherwise unable to cooperate with physical examination. Reassess again during the tertiary survey.

Eye Injuries

Corneal Abrasion

In spite of brisk protective reflexes, corneal abrasion is common. Although this is typically caused by rubbing or itching the eyes, it is also caused by scraping with twigs, broken glass, or sand, or by industrial accidents involving power grinders, saws, or welders. The patient will typically have a sudden onset of pain in the affected eye and a foreign body sensation in the eye, with increased tearing and blurry vision. Physical exam may reveal conjunctival injection and tearing; however, external inspection can also be normal. The eye should be examined with magnification, and an ultraviolet (UV) light source after fluorescein dye is instilled onto the conjunctiva. This should ideally be performed with a slit lamp, but a Wood's lamp can also be used if the patient is not capable of sitting up. Corneal abrasions appear as areas of increased dye uptake on the corneal surface (Figure 2.1). Anesthetic drops will also completely relieve the patient's pain. Most corneal abrasions will heal within 2–3 days, and although commonly prescribed, ocular antibiotic drops are not necessary for most cases.

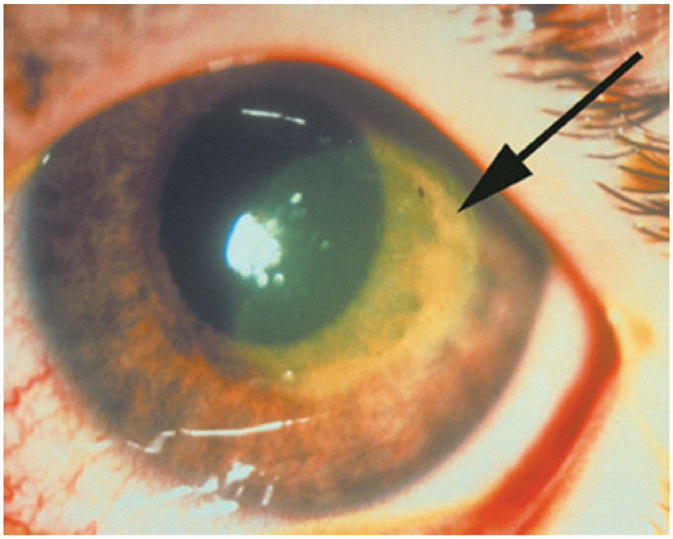

Figure 2.1 Photograph of a corneal abrasion after instillation of fluorescein dye showing bright yellow-green uptake of dye lateral to the pupil (arrow).

Ocular Foreign Body

Corneal abrasions may also be associated with a retained foreign body. If this is small and well visualized (e.g., small piece of metal, glass, or wood in the lid margin or on the cornea), it can be gently removed with the point of a needle under magnification in the emergency room. Irrigation should be performed to wash out the foreign body. A rust ring around a small piece of metal can form and interfere with the patient's vision. Importantly, any patient presenting with symptoms of corneal abrasion after use of industrial equipment, such as high-speed grinding or hammering on metal, should be suspected of having a perforated globe. Small metal fragments can enter the globe at very high speed leaving minimal evidence of entry on the surface. These are best diagnosed with orbital CT scan and, if found, should prompt ophthalmology consultation (Figure 2.2 A–D).

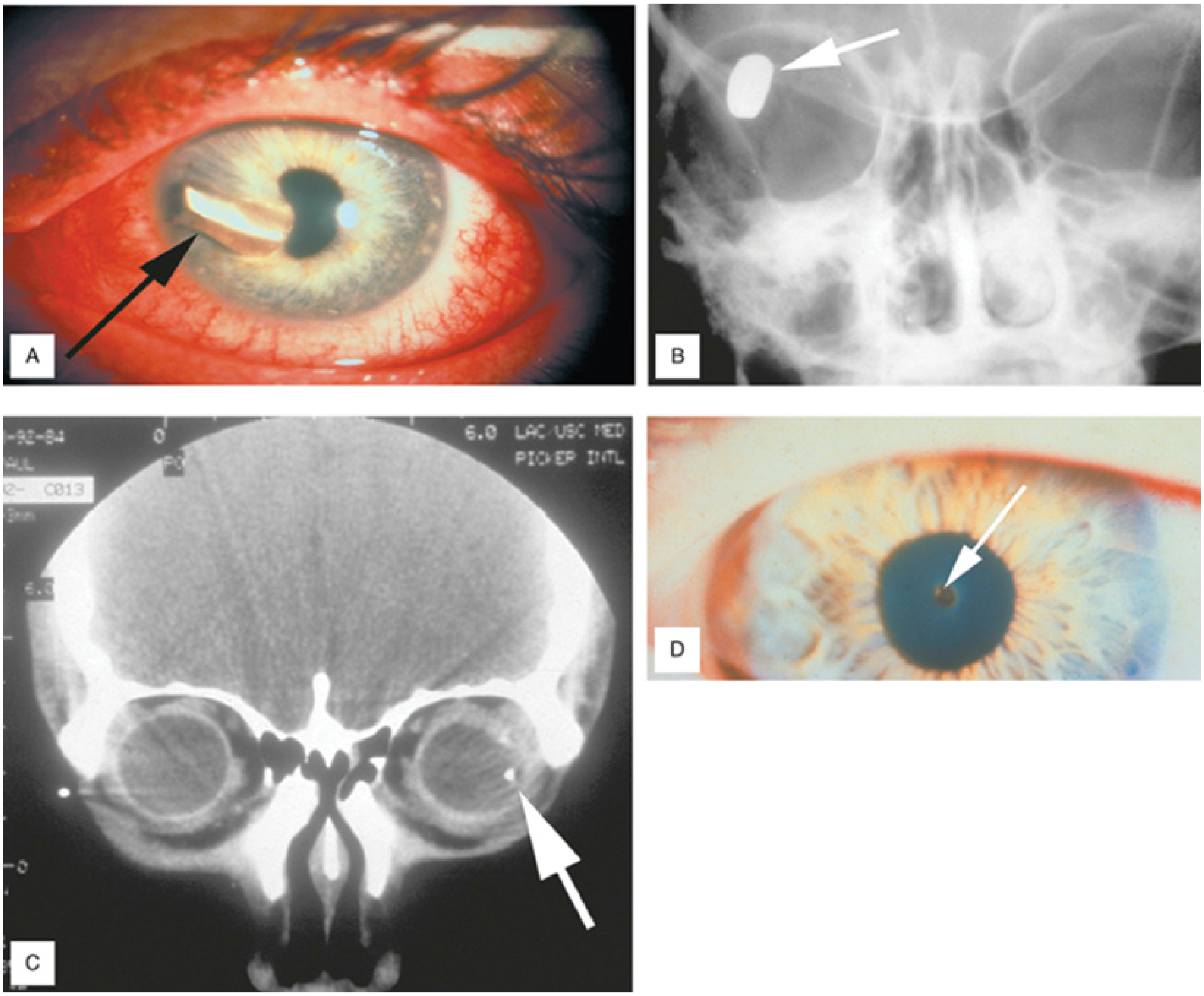

Figure 2.2 A–D Photograph of the eye showing a metallic foreign body on the cornea deforming the iris and the pupil (arrow; A). Plain radiograph showing an intraocular bullet (arrow; B). CT scan of the orbit showing one small intraocular foreign body of the left eye (arrow), and another lateral to the right orbit (C). Photograph of the eye showing a central rust ring in the cornea (arrow; D). This rust ring is in the visual axis and will seriously impair vision if not removed.

Hyphema

Hyphema is the accumulation of blood in the anterior chamber of the eye, most often due to direct trauma. The blood is most easily visible with the patient in a supine position when it forms a clearly visible layer in the dependent portion of the anterior chamber (Figure 2.3). Initial bleeding usually reabsorbs without complications; however, approximately one-third of cases exhibit rebleeding after several days. Complications from hyphema include hemosiderin staining of the inner surface of the cornea with resulting loss of vision, as well as posttraumatic glaucoma due to fibrotic occlusion of the canals of Schlemm. Treatment of posttraumatic glaucoma is conservative, including bed rest with head elevated, sedation, and monitoring of intraocular pressure. Surgery is required occasionally for evacuation of blood or to decompress the anterior chamber.

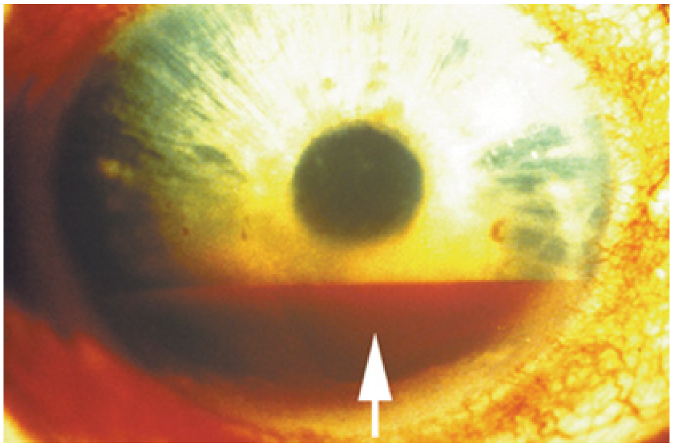

Figure 2.3 Photograph of the eye showing a collection of blood pooled (hyphema) in the inferior aspect of the anterior chamber (arrow).

Ruptured Globe

Globe rupture usually occurs after penetrating injury but can be caused by blunt trauma as well. Penetration of the sclera results in herniation of orbital contents through the wound and exposure of the choroid membrane, visible as a dark layer of tissue in the wound. Penetration of the cornea allows leakage of vitreous humor through the wound. In either case, distortion of the globe results in loss of functional vision at the time of injury, although light perception may be preserved. Patients report pain and often resist eye examination. Additional signs of globe rupture may include enophthalmos, loss of eyeball turgor, a peaked pupil that often points toward the site of injury, loss of pupillary reactivity, and a positive Seidel's test. Seidel's test is performed by instilling fluorescein dye into the conjunctiva and observing the dye as it clears from the cornea or sclera in the area of presumed rupture. This clearance is due to the flow of aqueous humor from the anterior chamber.

Although intraocular pressure is reduced in the presence of a ruptured globe, tonometry or any other maneuver that increases pressure on the globe is contraindicated. The conjunctiva is very distensible and often becomes edematous after trauma, resulting in bulging chemosis, which frequently limits a complete exam. Because of its common association with rupture of the globe, bulging chemosis itself should be considered a sign of possible ruptured globe. The ruptured globe is commonly enucleated if sight cannot be restored to avoid the development of a sympathetic ophthalmoplegia in the normal eye (Figure 2.4 A–E).

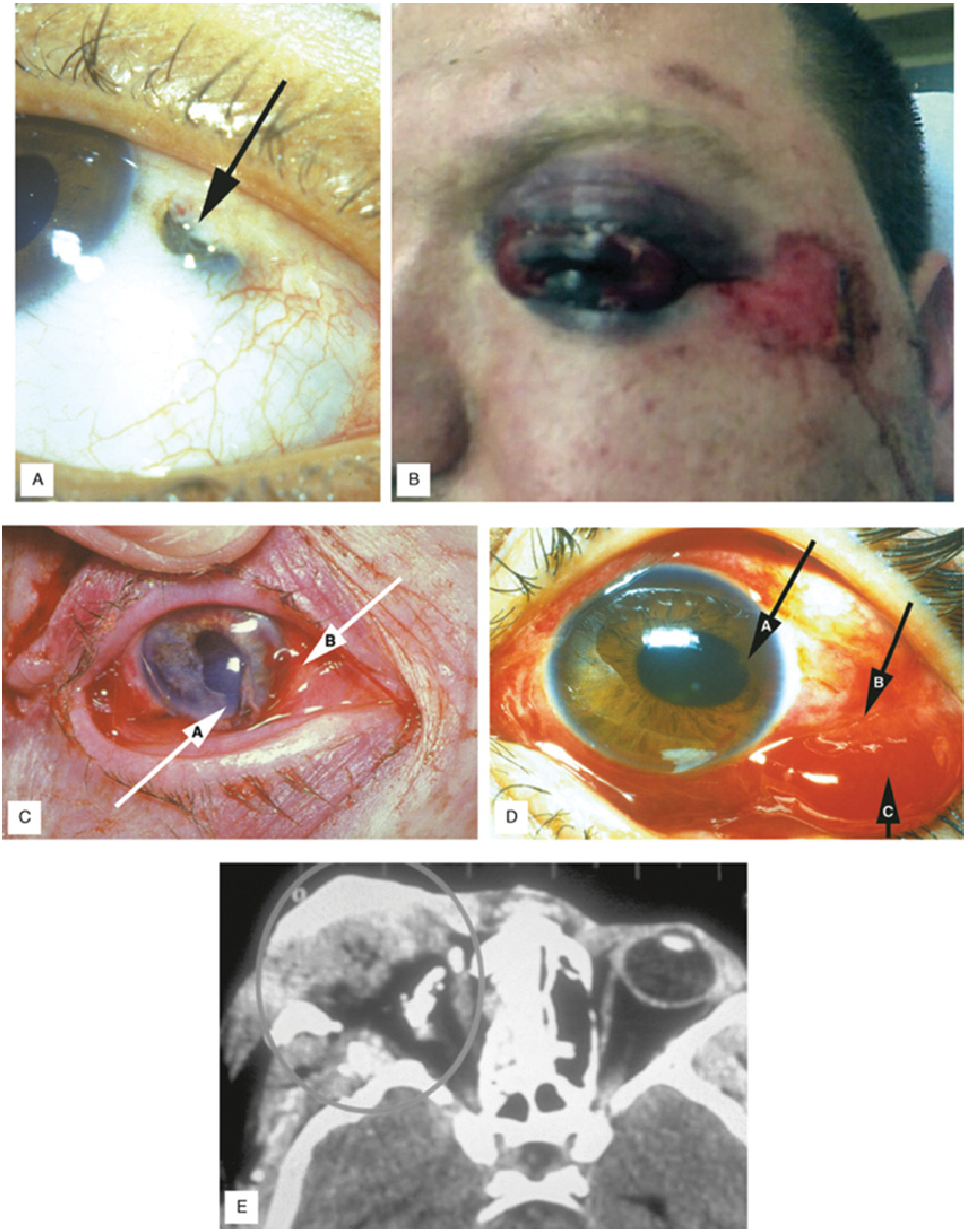

Figure 2.4 A–E Photograph of the eye showing a scleral laceration with exposure of the choroid (arrow). This is highly suggestive of rupture of the globe (A). Photograph of a patient with a ruptured globe from blunt trauma (B). Image courtesy of Manon Kwon, MD. Photograph of an irregular peaked pupil (arrow A), bulging chemosis (arrow B), and laceration of the iris due to a ruptured globe (C). Photograph of a ruptured globe with a peaked pupil (arrow A), laceration of the inferior/lateral sclera (arrow B), and bulging chemosis (arrow C). The peak in the pupil points toward the laceration (D). Gunshot wound of the right orbit with extensive destruction of the bone structures and the eye globe (E).

Retrobulbar Hematoma

Trauma to the globe can cause bleeding from retroorbital vessels, including the ophthalmic artery and vein. In addition, fractures of the orbit that communicate with the paranasal sinuses can result in the accumulation of air in the retroorbital space. As air or blood accumulates under increasing pressure, ischemic necrosis of the optic nerve can occur and can result in permanent loss of vision. Clinical evidence of this condition includes proptosis, impaired extraocular movements, and progressive loss of vision. Tonometry will indicate elevated intraocular pressure.

Treatment of a symptomatic retrobulbar hematoma is by lateral canthotomy with cantholysis or by surgically perforating the floor of the orbit to allow decompression of the retrobulbar space. Lateral canthotomy is performed by grasping and crushing the lateral canthal ligaments with a forceps. Cantholysis is then performed using iris scissors to divide the lateral canthal ligament, allowing the globe to protrude forward and release the accumulated retroorbital pressure. If done promptly, normal vision can be preserved and an ophthalmologist can subsequently reposition the globe and repair the canthal ligament. Alternatively, a forceps can be introduced beneath the globe and the floor of the orbit fractured to allow drainage of the retroorbital space into the maxillary sinus. However, this should typically be reserved for a specialist to avoid complications (Figure 2.5 A–C).

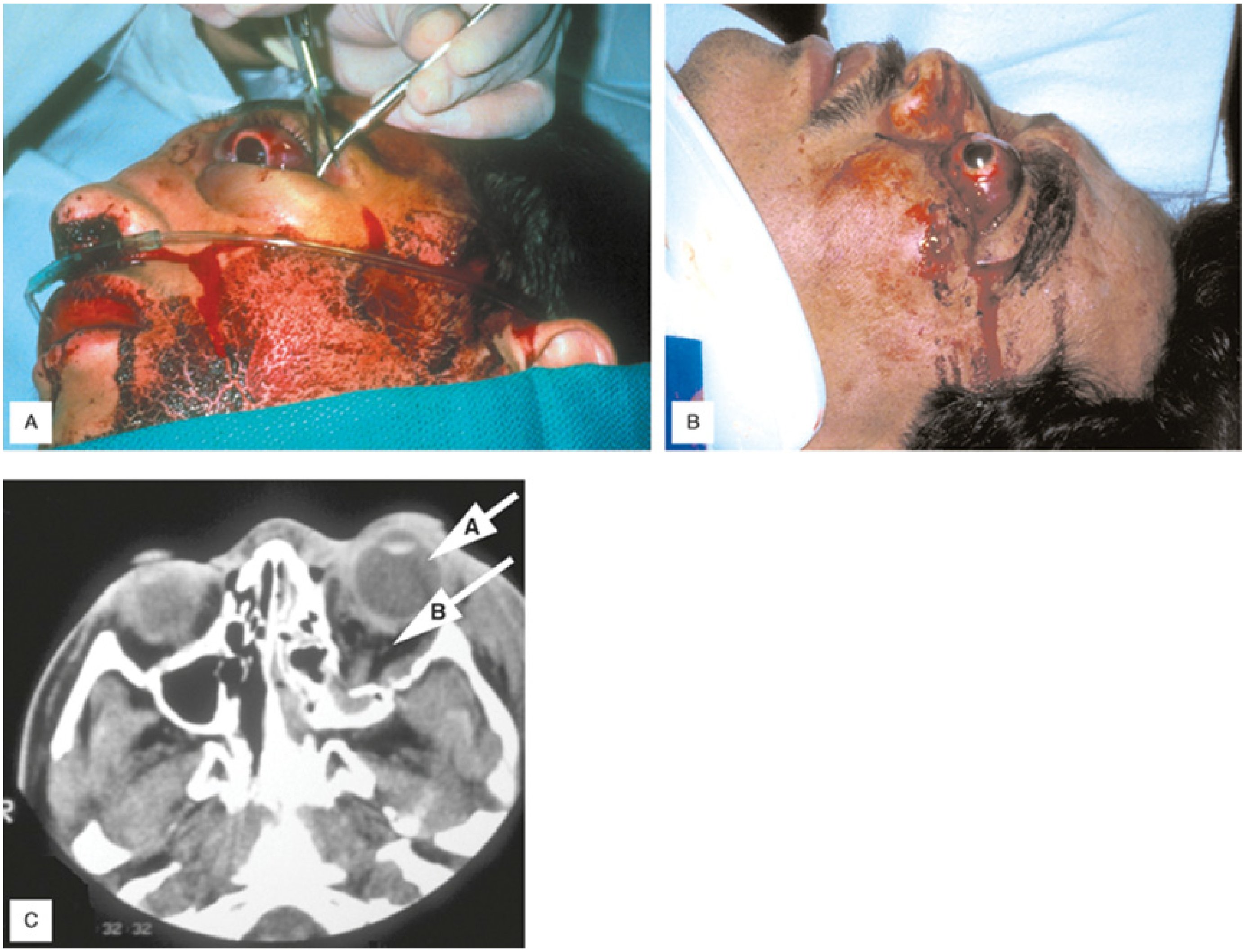

Figure 2.5 A–C Photograph of a lateral canthotomy in progress (A). Photograph showing increased proptosis of the eye after lateral canthotomy (B). Allowing the eye to protrude further decreases the retrobulbar pressure on the optic nerve. CT scan of the orbit showing proptosis (arrow A), retroorbital blood and air (arrow B), and a fracture of the posterior orbital wall (C).

Periorbital Laceration

In addition to the globe itself, there are numerous structures adjacent to the eye that merit special consideration as they may also sustain significant trauma. The lacrimal system ensures that a constant flow of tears stream across the surface of the eye, maintaining lubrication to facilitate ocular motion, preventing desiccation, and clearing debris, including potential infectious agents. Lacerations involving the lacrimal apparatus, lid margins, and lacrimal duct must all be sought out and referred to an ophthalmologist for repair. Lacerations of the lid margins are reapproximated exactly under microscopic vision to avoid a step-off that can result in constant dripping of tears onto the face. Injury to the lacrimal duct at the medial canthus of the eye is important to detect and repair, as scarring and stenosis of the duct can result in a similar problem. Delayed repair of a stenotic lacrimal duct is very difficult and yields suboptimal results in most cases, so it is important to promptly identify and refer these patients to an ophthalmologist.

Laceration of the eyebrow is common and can be repaired in the emergency department. Exact alignment is essential to preserve facial expression and symmetry of the hairline. Consequently, the eyebrows should never be shaved in preparation for suturing, as the alignment landmarks will be lost. Repair of each layer of tissue is done independently in a layered closure to preserve the mobility of the brow (Figure 2.6 A–C).

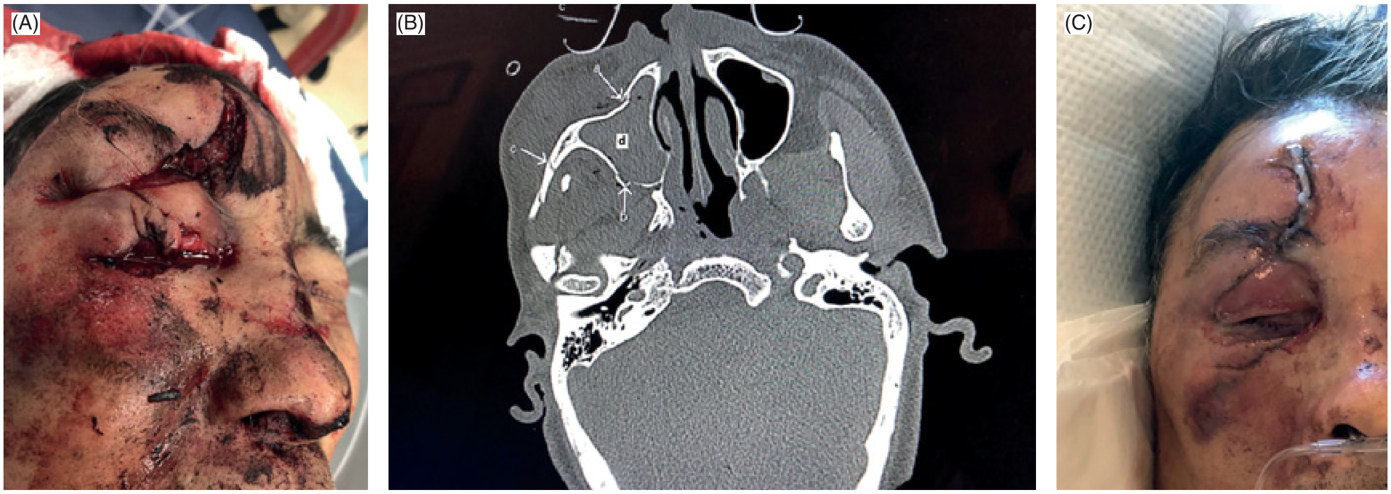

Figure 2.6 A–C Patient involved in auto versus pedestrian injury with severe facial trauma. Photograph of a complex laceration of the eyelids and forehead (A). CT scan demonstrates fractures of the maxillary sinus walls (arrows a, b), fracture zygoma (arrow c), and hemorrhage in the sinus (arrow e; B). Photograph of the patient after reconstruction (arrow C).

Facial Fractures

Orbital Wall Fracture

Orbital wall fractures are extremely common in the setting of blunt trauma. The globe itself is usually spared when large objects strike the face due to the protection afforded by the malar prominence, nose, and superior orbital ridge. However, objects can strike the globe directly, resulting in a massive rise in intraocular pressure. This pressure is transmitted to the bony orbit, and can result in a fracture at weak points, including the orbital floor and the medial wall of the orbit, often referred to as a "blowout fracture." The patient presents with enophthalmos and pain in the periorbital area. A common complication of this injury is entrapment of the inferior rectus muscle in the fracture fragments, resulting in restricted upward gaze and diplopia when looking up. An entrapped inferior rectus muscle requires urgent surgical repair. Isolated orbital wall fractures without associated muscle entrapment do not typically require urgent surgical repair and can be treated conservatively with continued monitoring for the development of enophthalmos. This should include sinus precautions in order to avoid complications including free air in the orbit. Orbital wall fractures are most commonly identified on maxillofacial or orbital CT scans. In addition to direct palpation of the fracture, a characteristic finding on CT scan includes opacification of the maxillary sinus due to herniation of periorbital fat and blood (Figure 2.7 A–F).

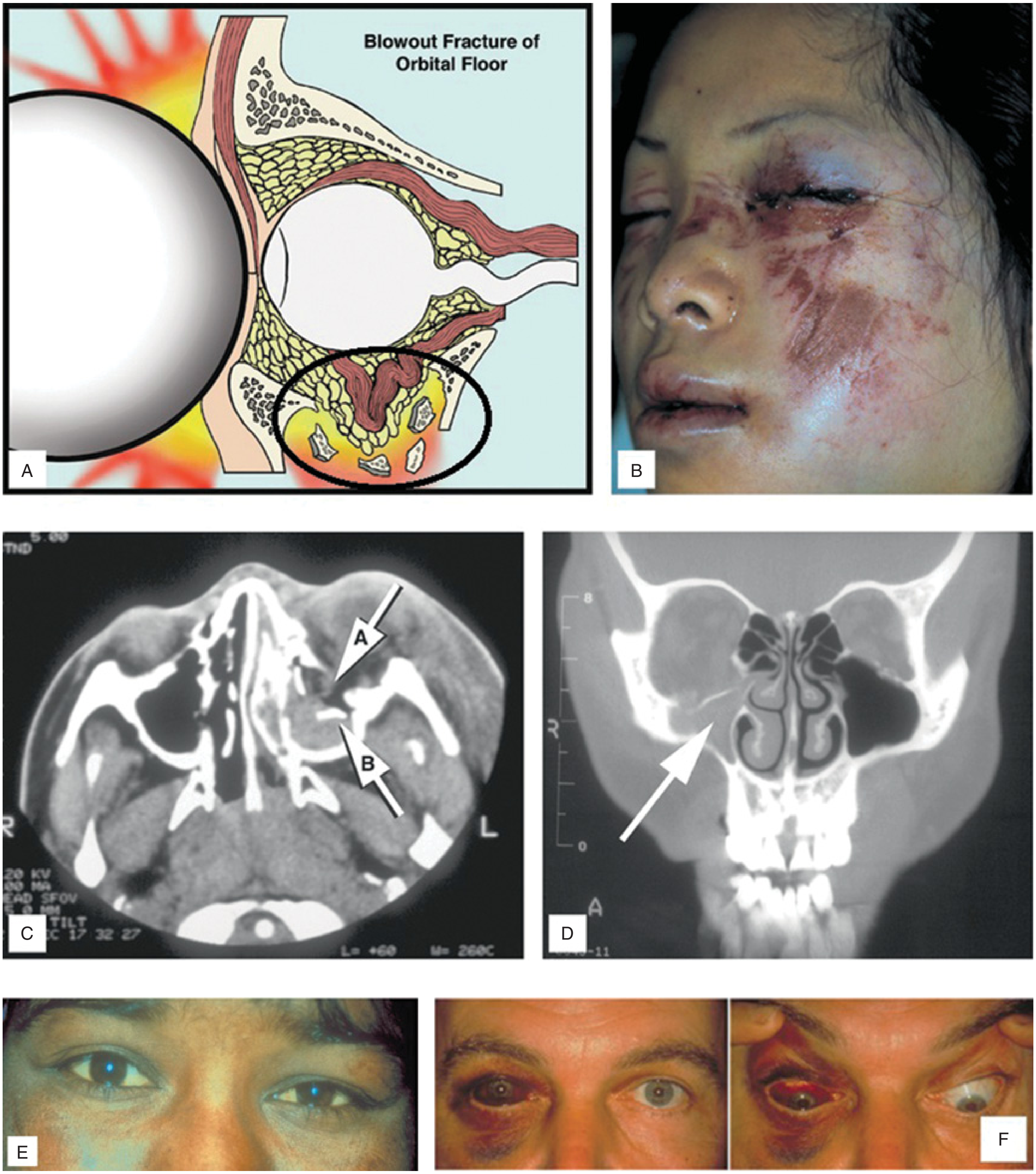

Figure 2.7 A–F Illustration showing typical mechanism of injury that produces an orbital blowout fracture (circle; A). Photograph of a patient with blunt trauma to the orbital area from an airbag deployment, who proved to have an orbital blowout fracture (B). CT scan of the orbits showing fracture of the posterior/inferior orbital wall (arrow A) with herniation of orbital contents into the maxillary sinus on the left (arrow B; C). CT scan showing fracture of the inferior orbital wall with opacification of the right maxillary sinus (arrow; D). Photograph of a patient with blowout fracture showing enophthalmos of the left eye (E). Photographs of a patient with a blowout fracture of the right eye and subconjunctival hemorrhage (F). There is no evidence of divergent gaze with the eyes in neutral position. Downward gaze reveals entrapment of the extraocular muscles of the right eye, resulting in a subtle divergent gaze.

Mandible Fracture

Fractures of the mandible are common after direct blunt facial trauma, such as motor vehicle accidents or assaults. The site of fractures is distributed almost equally at the condyles, angle, and body of the mandible. Patients typically present with swelling and tenderness over the fracture site, and crepitus can sometimes be appreciated. Dysarthria and drooling are also common symptoms. The patient may have trismus or note malocclusion of the teeth if the fracture fragments are displaced. On exam, the patient is often unable to pull back against a tongue blade with their teeth. Open fractures may be appreciated in the mouth, with gingival lacerations overlying the fracture site. Trauma to the temporomandibular joint is common and may result in dislocation of the joint or chronic pain with chewing. Finally, airway obstruction is possible in unconscious patients with bilateral mandibular rami fractures, as the tongue is unsupported and can fall back into the posterior pharynx.

Maxillofacial CT scan is the imaging modality of choice in most emergency departments, as this is almost universally available. However, if panorex X-ray views of the jaw are available, this is more accurate and should be used. Treatment is operative, with wiring or plating of the fracture fragments into anatomic position. An appropriate specialist, such as an oral maxillofacial surgeon, can often perform this at the bedside. Open fractures of the mandible should be treated with antibiotics that are active against mouth flora because osteomyelitis and abscess formation can occur (Figure 2.8 A,B).

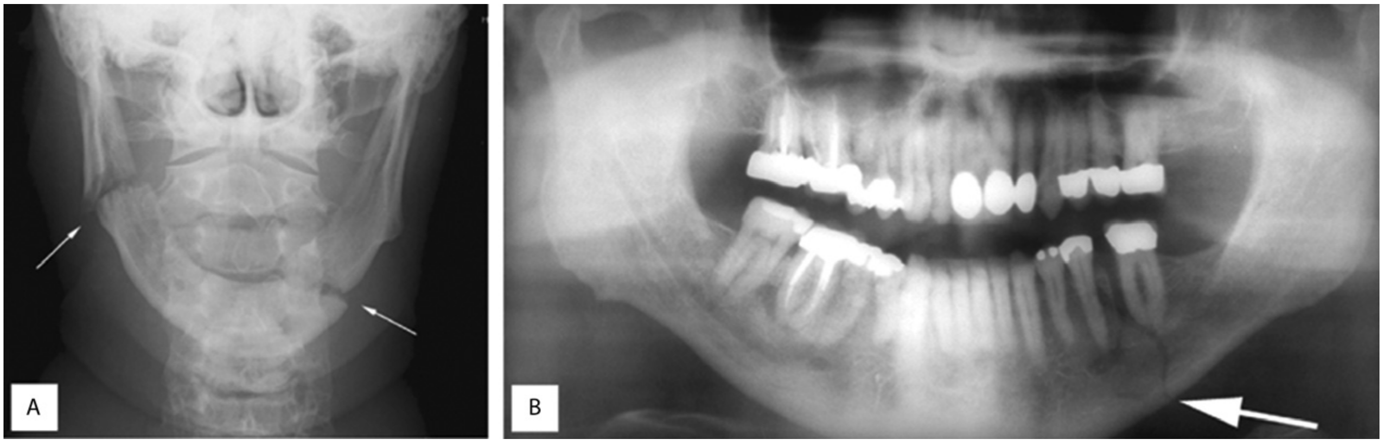

Figure 2.8 A,B Anteroposterior radiograph of the mandible showing bilateral displaced fractures of the angles of the mandible (arrows; A). Panorex view of the mandible showing an undisplaced fracture of the left mandibular ramus (arrow; B).

Zygoma Fracture

The zygoma provides the bony support to the cheek and thus is commonly implicated in blunt trauma to the face. Because of its arched structure, comminuted fractures are often seen. The patient typically presents with loss of the malar prominence on the affected side. Shortly after injury, however, swelling may mask this finding, so careful palpation of the facial bones to detect pain, bony step-offs, or crepitus of the zygoma should be performed. Impingement of the zygoma onto the coronoid process of the mandible may result in limited excursion of the mandible and consequent trismus. An associated injury to the infraorbital nerve is also possible and typically results in anesthesia of the upper lip.

As with other facial fractures, diagnosis should be made with maxillofacial CT, as this is more sensitive than plain radiographs. Treatment of displaced zygoma fractures is surgical elevation of the fragments, with the objective of restoring a normal facial contour.

A complex variant is called a tripod fracture. This involves fractures at the three origins of the zygoma, specifically at the zygomaticofacial and zygomaticofrontal sutures and through the inferior orbital foramen. This results in a free-floating fragment of bone that typically requires surgical repair. Because this injury often involves the infraorbital foramen, hypoesthesia of the ipsilateral mid-face extending to the upper lip is often present (Figure 2.9 A,B).

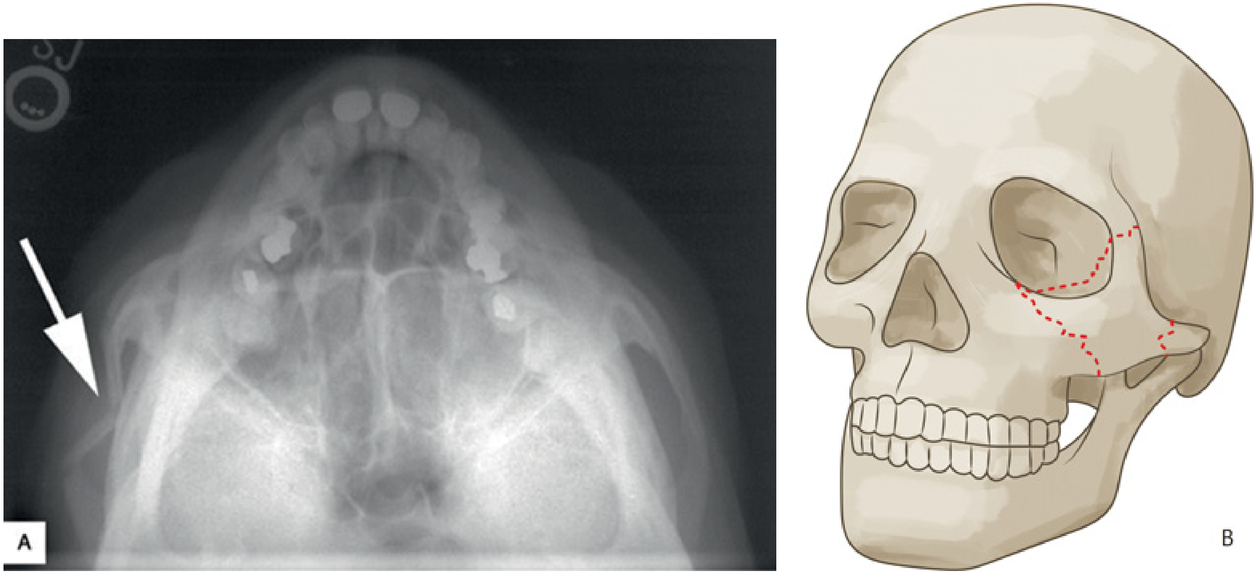

Figure 2.9 A,B Submentovertex plain radiograph showing a depressed right zygomatic arch fracture (arrow; A). Illustration outlining a tripod fracture of the zygoma (B).

Le Fort Fracture

Le Fort fractures result from high-energy facial trauma and are classified according to their location in the mid-face.

The *Le Fort I fracture* separates the upper alveolar ridge from the face and extends into the nasal fossa. Clinically, the patient will have mobility of the upper teeth when they are grasped and pulled forward. This fracture is rarely associated with airway compromise.

The *Le Fort II fracture* separates the mid-face from the skull, resulting in a large pyramid-shaped fragment of the central maxilla and nasal bones. Pulling on the upper teeth demonstrates mobility of the entire mid-face. CT imaging reveals fracture lines through both maxillae extending upward to include the nasal bones. Associated basilar skull fracture is common, and CSF rhinorrhea can occur. Massive epistaxis may require nasal packing or surgery to control.

The *Le Fort III* fracture is the most severe form and results in complete craniofacial dissociation due to fractures of bilateral maxillae, zygomas, nasal bones, ethmoids, and vomer, as well as bones at the base of the skull. Complications such as intracranial injury, airway compromise, basilar skull fracture, cervical spine injury, CSF rhinorrhea, and massive epistaxis are common due to the high-energy mechanism required to sustain this type of fracture. Nasal intubation and nasogastric tubes should be avoided because of the risk that they will be fatally inserted intracranially. Both Le Fort II and III fractures are potentially life-threatening, as they are commonly associated with airway compromise, massive bleeding, basilar skull fracture, and intracranial injury (Figure 2.10 A–D).

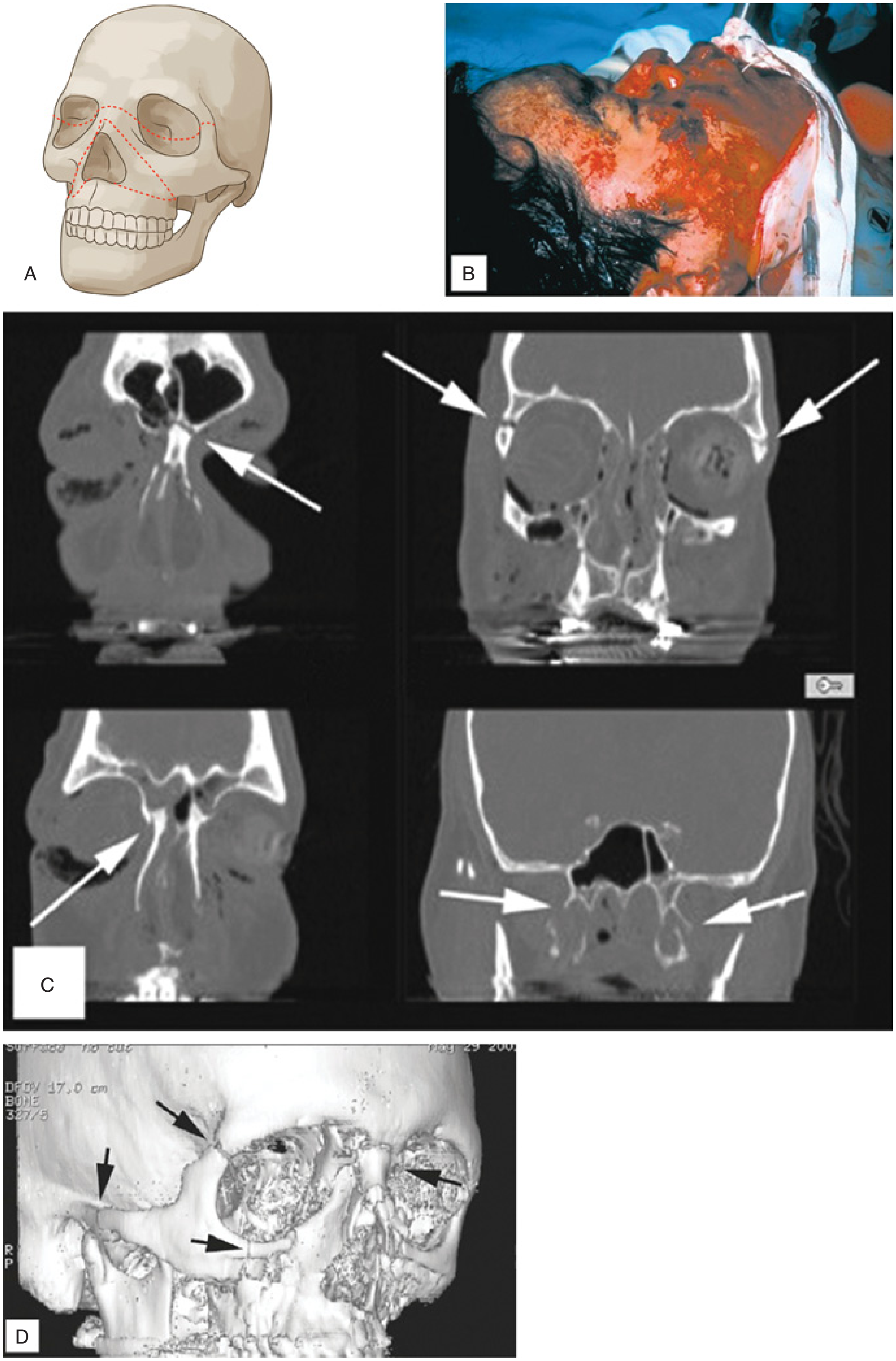

Figure 2.10 A–D Schematic showing three types of Le Fort fracture (A). Photograph of a patient who had a garage door crush his face. The abnormal concavity of the face ("dish face") is characteristic of a Le Fort III fracture (B). CT scan of the face showing Le Fort III fracture: (a) anterior ethmoid fracture (arrow), (b) mid ethmoid and lateral orbit fractures (arrows), (c) frontal sinus fracture (arrow), and (d) pterygoid fractures (arrows; C). CT scan 3-D reconstruction of a Le Fort III fracture showing multiple fractures, including a tripod fracture of the zygoma (arrows; D).

Nasal Injury

Superficial lacerations of the nose are common and easily repaired. Laceration extending through the nasal cartilage must be repaired with separate layers using absorbable sutures for the cartilage repair. Avulsed cartilage should be preserved in saline if the repair can be done urgently or in a subcutaneous pocket if repair is delayed. Reconstruction of the nose can be done in a delayed fashion, but finding appropriate cartilage for reconstruction is difficult (Figure 2.11).

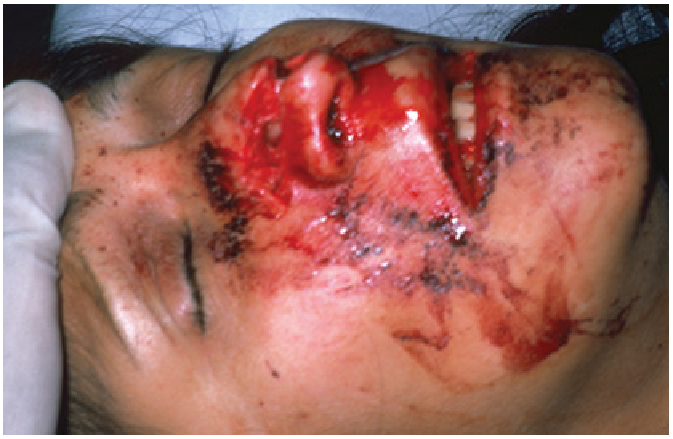

Figure 2.11 Photograph of a laceration through the nasal cartilage.

Nasal bone fractures may be treated conservatively if not displaced. It is typically not necessary to obtain imaging in the ER for isolated nasal bone fractures, as these can be diagnosed clinically and imaging will not affect acute management. Patients should be educated to allow initial swelling to resolve and if persistent deformity or asymmetry is present to follow up with a surgeon for cosmetic repair.

Deviation of the septum or impairment of nasal breathing is an indication for repair within the first week after injury. Open fractures should be treated with antibiotics. The nasal septum should be inspected for the presence of a nasal septal hematoma, which appears as a swollen, ecchymotic area separating the nasal mucosa from underlying cartilage. The hematoma must be drained, and the nose should be packed to avoid reaccumulation of the hematoma. If not drained appropriately, ischemic necrosis of the cartilage may result and can eventually lead to a saddle-nose deformity.

Penetrating Facial Trauma

While the vast majority of facial trauma is blunt in nature, penetrating wounds of the face due to gunshots, stab wounds, or impalement injuries also frequently occur.

The face is divided into three zones, each with structures at particular risk from penetrating injury. Zone I extends from the hairline to the superior orbital ridge and includes the ears. Injuries in this area are at risk for intracranial penetration and wounds of the frontal sinuses are at risk for serious infection. Zone II extends from the superior orbital ridge to the upper lip. Wounds in this zone are at risk for arterial injury, globe damage, and airway compromise. Zone III extends from the upper lip to the hyoid bone. Injuries in this area are at high risk for airway compromise and carotid artery injuries.

Airway assessment should be the first priority in examining patients with penetrating facial trauma. If suction of blood and debris from the airway does not restore adequate ventilation, orotracheal intubation is indicated. This may be difficult due to distorted anatomy and copious bleeding into the oropharynx. Surgical cricothyroidotomy may be required. Arterial bleeding may be readily apparent as pulsatile hemorrhage of bright red blood, but more often, it is apparent indirectly. Arterial injury is often inaccessible to vascular clamping or even direct pressure if it occurs deep to the bony facial structures. For example, an injury within the maxillary sinus may present as massive oral bleeding or epistaxis. The presence of an expanding or pulsatile hematoma is another indication of potential vascular injury.

Diagnosis of penetrating injuries relies heavily on CT imaging. In addition to a head CT, specific views of the orbits and facial bones may be indicated. CTA is indicated for suspected vascular injuries. The location of missiles is important because the irregular angles of facial bones and the base of the skull can deflect bullet fragments away from their expected course.

Treatment of penetrating facial injuries ranges from simple wound care and suturing of superficial lacerations to operative repair of more extensive injuries. Early debridement and operative fixation of fractures can be undertaken if the patient is sufficiently stable. Examination of the parotid duct, branches of the facial nerve, and major vessels is best done in the operating room. In rare cases, uncontrollable hemorrhage may require ligation of the ipsilateral external carotid artery (Figure 2.12 A–E).

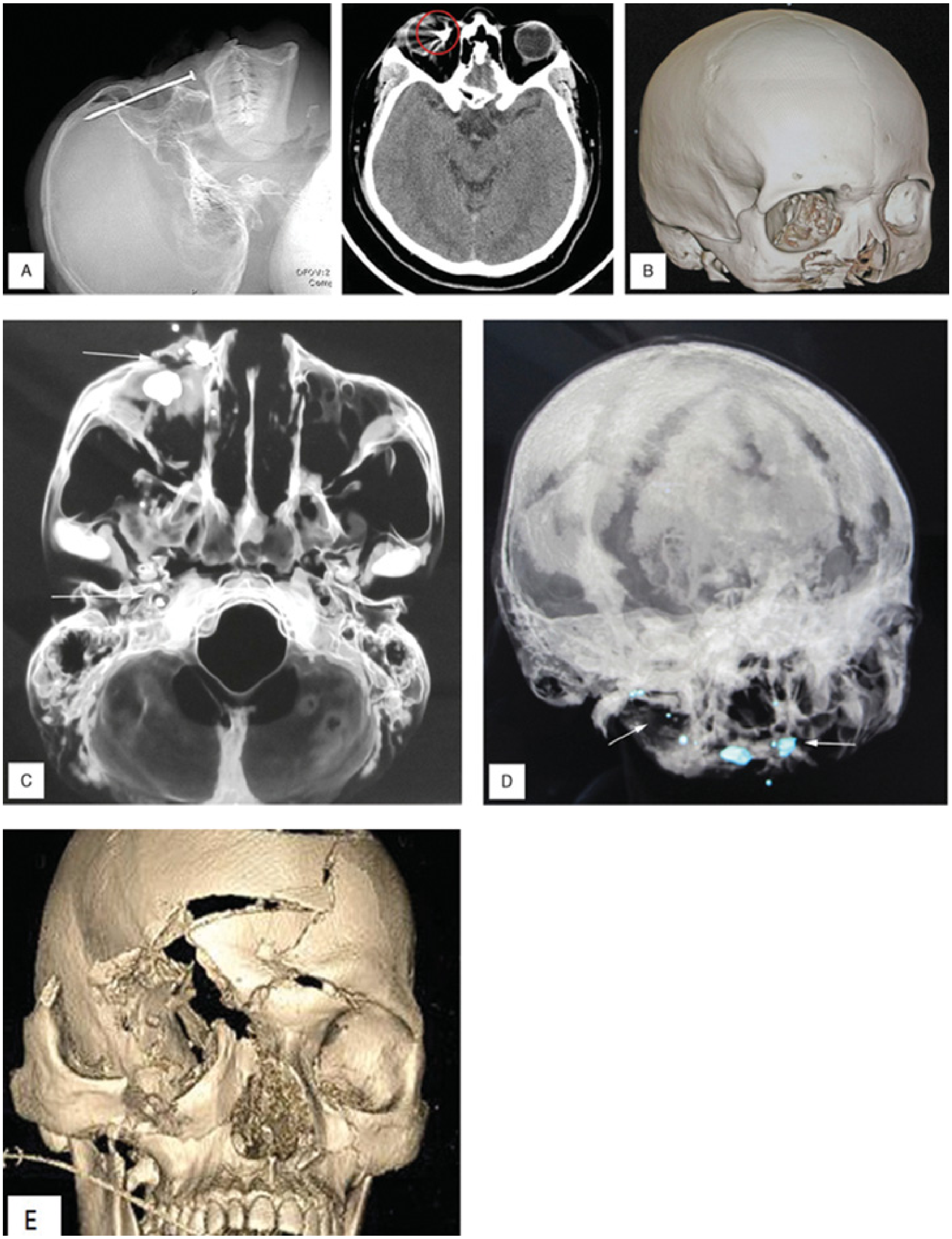

Figure 2.12 A–E CT scout film of the head showing a large nail penetrating through the face into the frontal lobe of the brain (left; A). The patient complained of diplopia and a 5 mm infraorbital entrance wound. He stated he had fallen off his bicycle 2 days earlier. CT scan of the same patient showing the metal foreign body medial to the globe. There was a small laceration of the globe, but the patient's sight was preserved and there were no apparent neurological deficits (right). CT scan reconstructions showing a gunshot wound of the face with a complex fracture of the zygoma and a bullet path through the orbit (B). CT reconstruction showing bullet fragments impacted at the anterior maxillary wall and extending posteriorly to the base of the skull (arrows; C). CT reconstruction highlighting the bullet fragments (D). CT scan 3-D reconstruction showing extensive facial and cranial fractures (E).

Complex Oromaxillofacial Trauma

Massive facial injury can result from blunt force trauma or penetrating injury from gunshot wounds. The primary challenge in these cases is to secure an airway. Massive facial injury can result in airway obstruction either by loss of the supporting bony framework of the face or by accumulation of blood, debris such as fractured teeth, edema, or tissue flaps that occlude the larynx. Immediate restoration of a patent airway is the highest priority in trauma management. Initially, simple airway maneuvers such as chin lift, suctioning blood and secretions, and placement of an oral airway should be attempted. If these are unsuccessful in restoring airflow, a definitive airway must be obtained rapidly. Orotracheal intubation is difficult because of massive bleeding and edema, distorted anatomic landmarks, and debris, including avulsed teeth, fragments of bone, and bullet fragments. Use of paralytic agents for orotracheal intubation may cause loss of voluntary muscle maintenance of a patent airway but, on the other hand, will facilitate intubation in a struggling, hypoxic patient. Attempted awake orotracheal intubation, although often recommended in these cases, is similarly extremely difficult and usually unsuccessful. Consequently, use of a cricothyrotomy is often the only viable choice to establish a patent airway and should be employed early in the management (Figure 2.13 A–D).

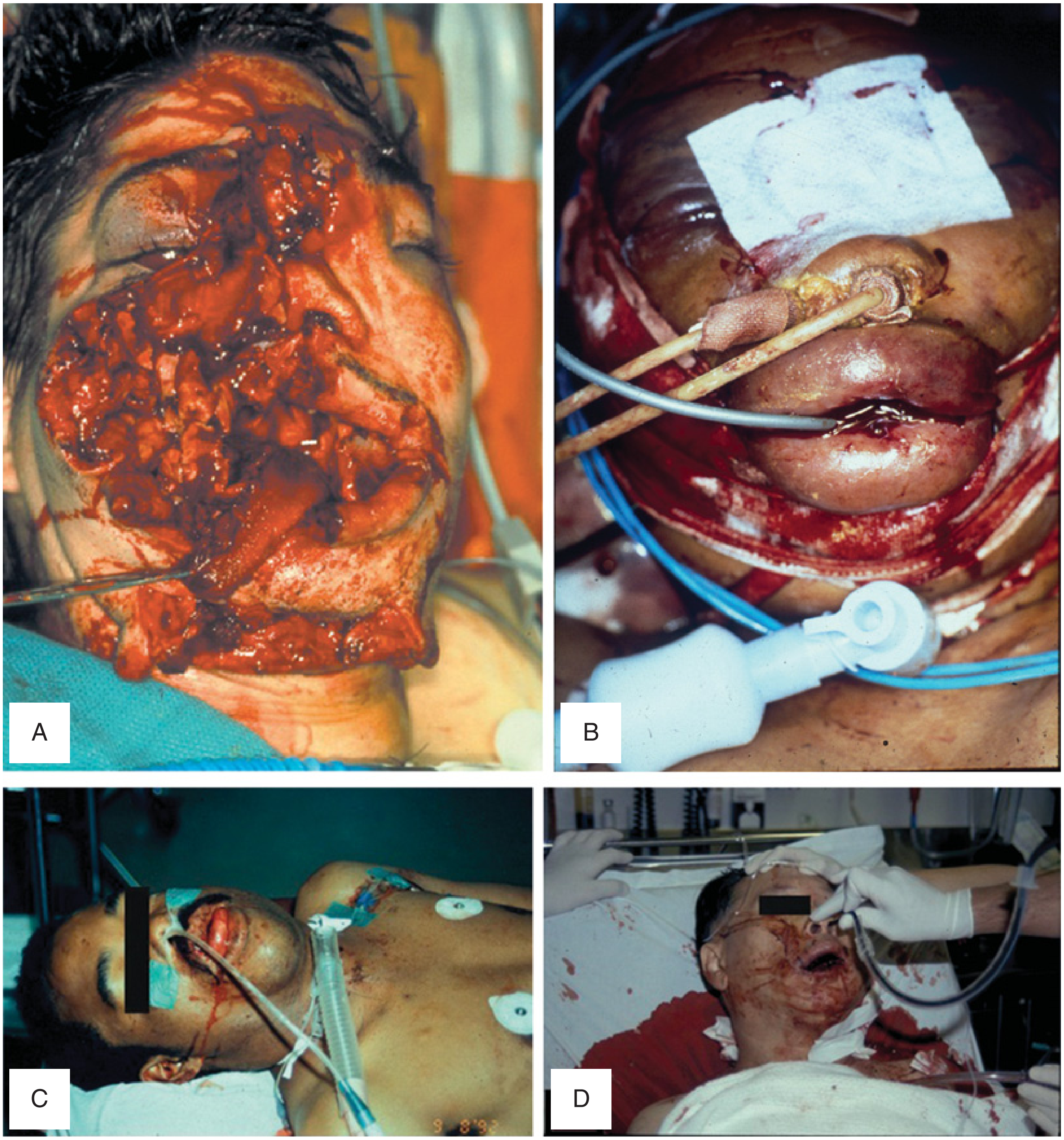

Figure 2.13 A–D Photograph of a patient with a shotgun wound of the face (A). Airway management is extremely difficult in these cases, as anatomic landmarks are severely distorted. Massive oromaxillofacial trauma with severe edema and airway obstruction. The patient needed a cricothyroidotomy (B). Gunshot wound to face with a large hematoma causing airway obstruction. The patient required an emergency cricothyroidotomy (C). Fiberoptic endotracheal intubation in a patient with gunshot wound of the face and extensive hematoma and bleeding (D).

Once the airway is secured, the spine is immobilized and the remainder of the primary survey and resuscitative interventions are completed. Massive facial injuries are dramatic and often distract clinicians from a systematic primary survey. Unless there is massive bleeding present, repair of the vast majority of facial injuries can be deferred until the patient is stable. Repair of facial lacerations can produce surprisingly good results, providing that tissue has not been avulsed and the arterial supply is intact. Debridement of tissue should be kept to a minimum, and tissues should be closed in layers, with individual muscle layers, subcutaneous tissues, and skin closed separately. Fine sutures with minimal inflammatory properties are used to close the skin. Revision of wounds should attempt to orient wounds parallel to the natural wrinkle lines of the face, as these scars will be less noticeable. Scars that are perpendicular to the natural wrinkle lines are much more apparent.

Oral Trauma

Lacerations of the lips occur commonly, as the lip can be crushed between a striking object and the underlying teeth. Simple lacerations typically heal well due to good blood supply to the lips. However, care must be taken to properly align lacerations that traverse the vermilion border because even minor misalignment in this area is noticeable and disfiguring (Figure 2.14 A–D).

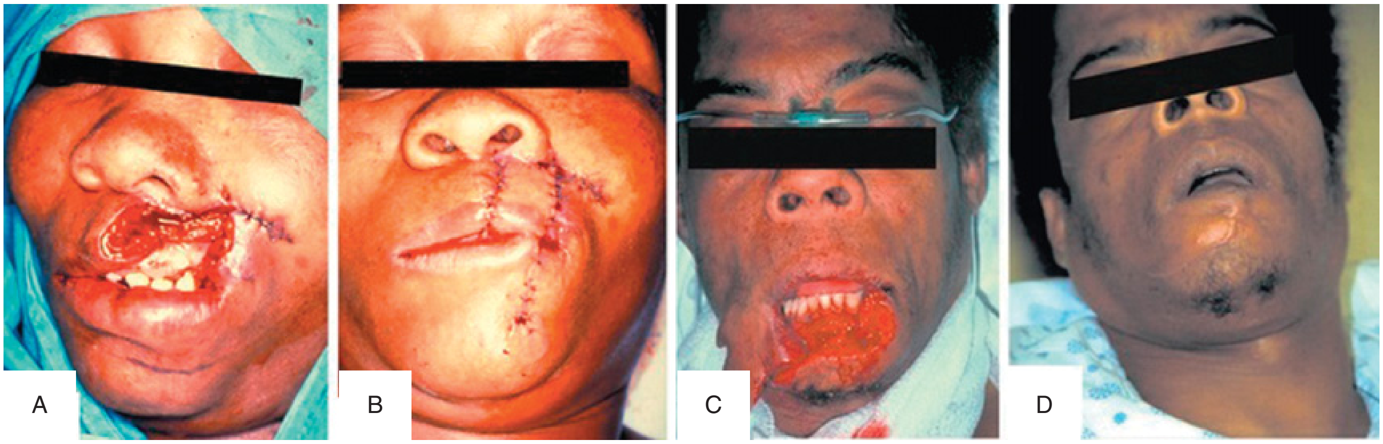

Figure 2.14 A–D Photographs of a patient with a complex facial laceration involving loss of tissue from the upper lip with avulsion of almost half the upper lip (A). After careful alignment of the vermilion border and restoration of the "cupid's bow," an acceptable cosmetic result is obtained (B). Photographs before (left) and after (right) repair of a complex laceration of the lower lip caused by a human bite (C). An acceptable cosmetic result is obtained (D).

Intraoral lacerations should be repaired using soft, absorbable sutures. With through-and-through lacerations involving the skin and mucosal surfaces of the mouth, the mucosal laceration is repaired first, followed by skin closure. Lacerations of the tongue should be repaired using absorbable sutures after removal of clots and irrigation of the wound. Because of its rich vascularity, the tongue is capable of massive swelling, and delayed airway compromise is possible.

It is also important to pay careful attention to any dental trauma that may have occurred, typically due to direct blunt trauma to the teeth. Dental trauma is often diagnosed on exam but may also be detected on CT imaging. Panorex radiographs may also be obtained to provide more detailed images. Various types of dental trauma can occur, including tooth fractures, avulsions, or luxation (tooth displacement). Dental fractures can be classified according to the Ellis classification system. Ellis 1 fractures involve superficial enamel only and do not require emergent dental care. Ellis 2 fractures involve both enamel and dentin and are typically air and temperature sensitive. These should be covered with dental cement and referred for urgent dental follow up. Ellis 3 fractures penetrate to the pulp and can be extremely painful. These should be covered with dental cement and have immediate dental follow-up. In the case of a dental avulsion in adults, the tooth should be reimplanted as soon as possible or placed in an appropriate medium until emergent dental consultation is obtained. With appropriate management, avulsed teeth do have a chance of successful reimplantation. Finally, if teeth are loose or displaced (luxations), they can be splinted in place with dental cement and should be referred to a dentist for further management.

Missing teeth should be accounted for, and X-rays of the neck, chest, and abdomen should be obtained to exclude aspiration or retained foreign bodies in soft tissue. In cases of aspiration in the tracheobronchial tree, the tooth should be removed to avoid infectious complications (Figure 2.15 A–C).

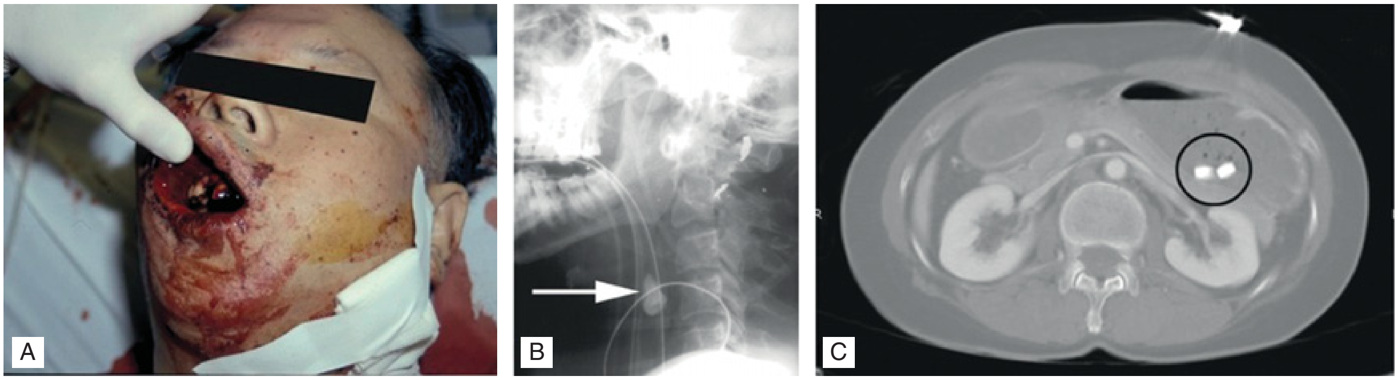

Figure 2.15 A–C Patient with gunshot wound to the mouth and missing teeth. This patient should undergo radiological evaluation of the neck, chest, and abdomen to locate the missing teeth (A). Lateral radiograph of the soft tissues of the neck showing an aspirated tooth anterior to C-4 (B). CT scan showing two avulsed teeth in the stomach (C).

Facial Nerve (Cranial Nerve VII) Injury

Penetrating facial trauma can occasionally result in transection of the facial nerve. The facial nerve exits the base of the skull, enters the face just anterior and inferior to the tragus of the ear, and continues as a large trunk for approximately 1 cm before it subdivides into an upper and lower division. Each division then branches extensively into smaller branches to innervate the muscles of the face. Lacerations in the vicinity of the tragus should prompt careful examination of the muscles of facial expression because facial nerve injury is frequently missed during the initial examination of patients with trauma. Injury of the smaller branches of the facial nerve may also merit exploration and surgical repair if they are lateral to the lateral canthus of the orbit. Care should be taken to moisten the conjunctivae with artificial tears, using an eye moisture chamber to avoid desiccation and ulceration of the cornea due to incomplete closure of the eyelid (Figure 2.16 A–D).

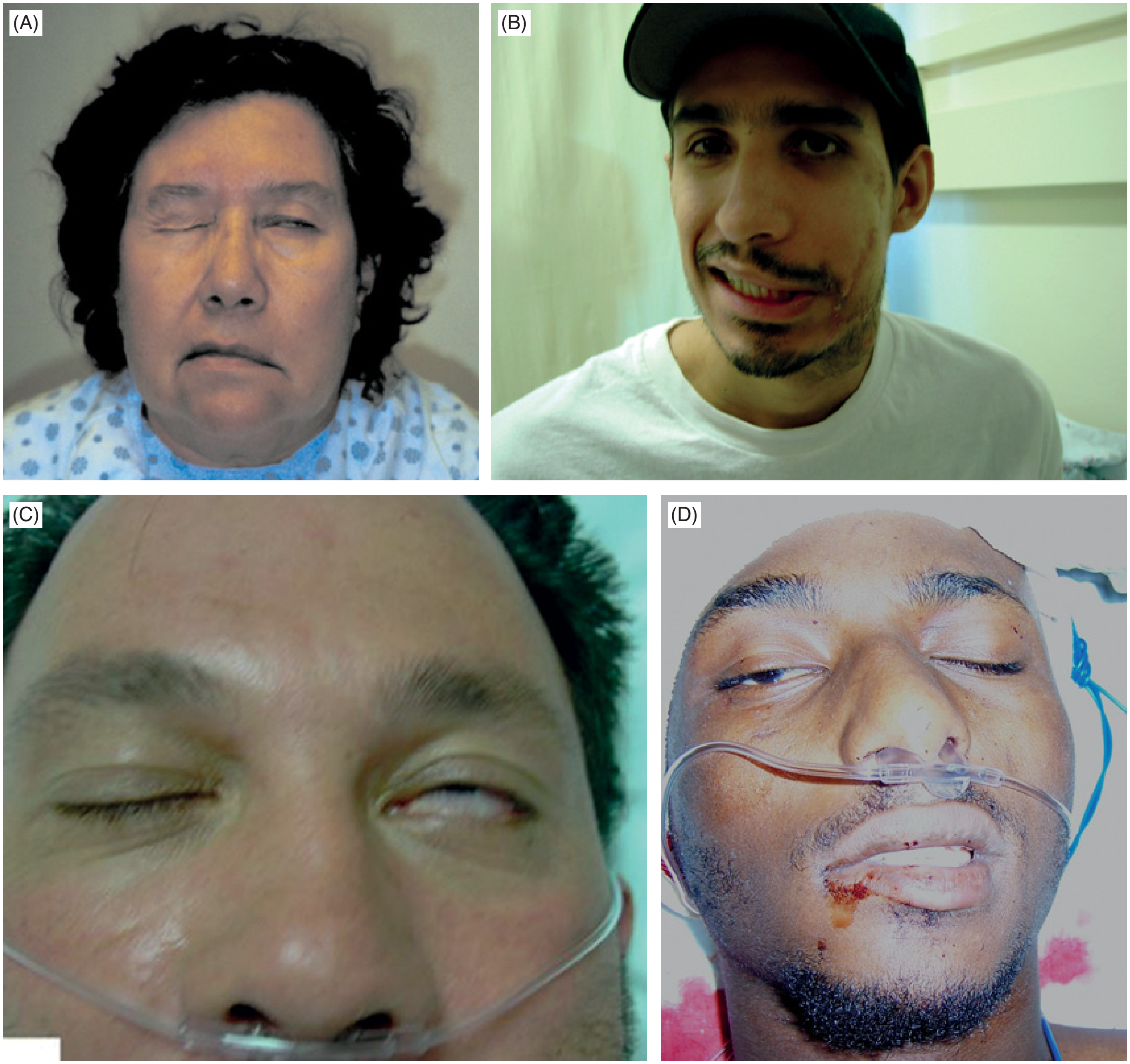

Figure 2.16 A–D Photograph of a patient with facial nerve injury on the left side showing loss of the left nasolabial fold, incomplete eyelid closure, and facial droop (A). Left facial nerve paralysis due to a stab wound (B). Note deviation of the mouth to the opposite side. Peripheral left facial nerve paralysis (C). Note the inability to close the ipsilateral eye. Right facial nerve injury with inability to close the right eye and deviation of the mouth to the opposite side (D).

Parotid Gland Injury

The parotid gland lies anterior to the tragus of the ear and extends to the mid-pupillary line external to the maxilla. Lacerations of the parotid gland may result in delayed sialocele or salivary cutaneous fistula. Laceration of the parotid duct, however, commonly results in persistent fistula. The parotid duct courses through the parotid gland along a line drawn from the tragus to the upper lip and enters the mouth as Stensen's duct at the level of the second upper molar. Lacerations that cross this line proximal to the entry of the parotid duct into the mouth should be suspected of transecting the duct. Examination of the duct is performed by milking the parotid gland while examining Stensen's duct intraorally. Expression of saliva suggests that the duct is intact. Expression of blood or failure to express saliva suggests transection of the duct. If injury is suspected, Stensen's duct is probed retrograde, and the wound is examined for the probe. Careful surgical repair of the duct will prevent the formation of a salivary-cutaneous fistula (Figure 2.17 A,B).

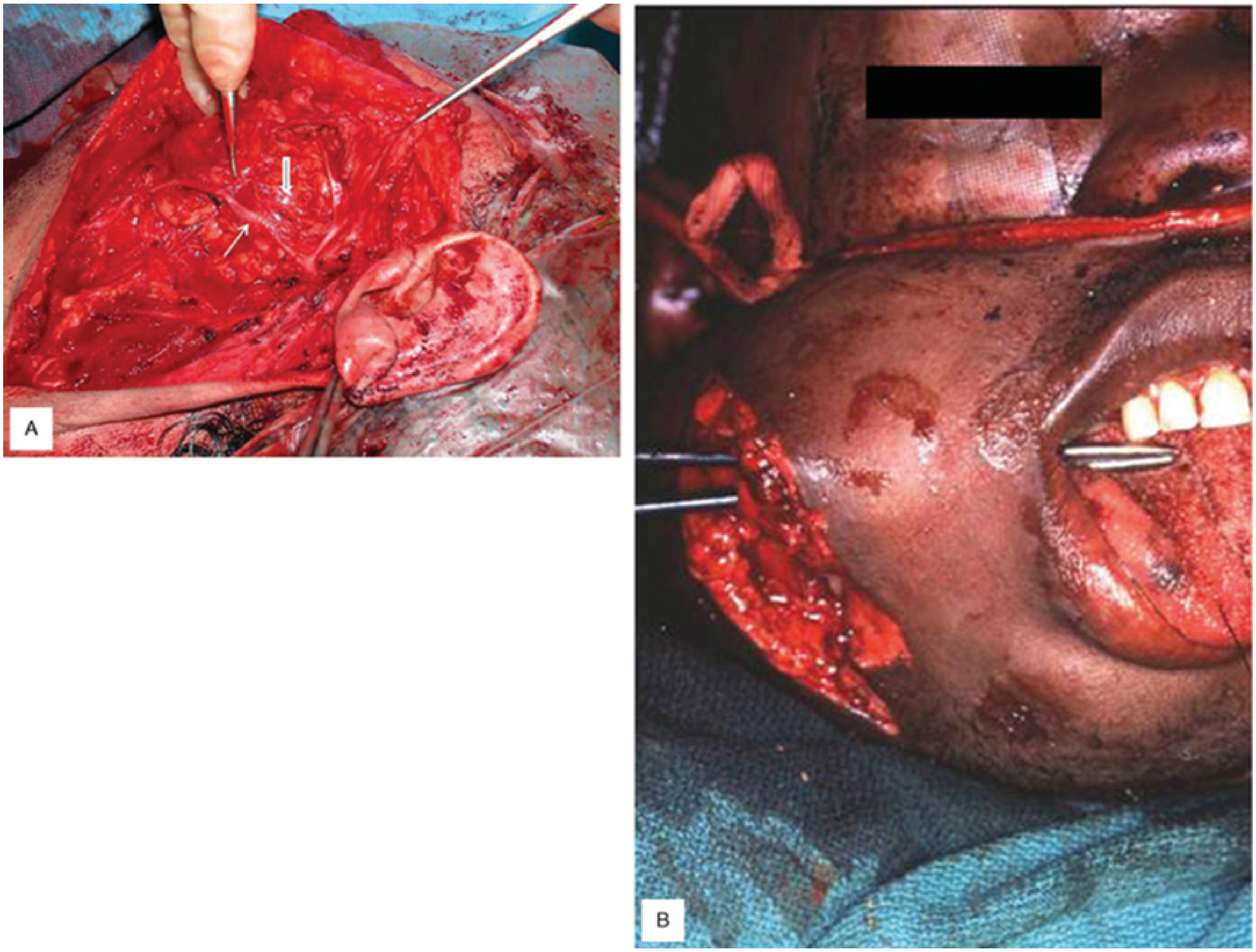

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Figure 2.17 A,B Repair of the inferior branch of the right facial nerve (white arrow) and the right parotid duct (wide arrow) following transection from a facial laceration (A). Patient with extensive right facial nerve and parotid gland injuries (B). Neither structure could be repaired, due to the extensive damage to the parotid gland. Images (courtesy of Dr U. Sinha).

Chapter

3

Neck Injury

Demetrios Demetriades and Lydia Lam

Introduction

Neck injuries, particularly those due to penetrating trauma, are difficult to evaluate and manage due to the dense concentration of vital structures in a small anatomical space that can be surgically challenging to access. Only 15–20% of patients with penetrating trauma and very few with blunt mechanism require operative intervention. Meticulous clinical examination and well-selected diagnostic investigations are paramount to safely selecting those patients who require an operation and those that can be observed.

During the primary survey, the following life-threatening conditions in the neck should be identified and treated:

1. Airway obstruction due to laryngotracheal trauma or compression by external hematoma
2. Tension pneumothorax, especially in patients with penetrating trauma in the supraclavicular area
3. Severe active bleeding, externally or into the thoracic cavity
4. Spinal cord injury
5. Ischemic brain damage due to carotid artery occlusion

During the secondary survey, the following neck pathologies should be identified and managed:

1. Occult vascular injuries
2. Occult laryngotracheal injuries
3. Occult pharyngoesophageal injuries
4. Cranial or peripheral nerve injuries
5. Small hemopneumothoraces

Clinical Examination

Clinical examination according to a carefully written protocol is the cornerstone of the neck trauma diagnosis and management. The examination should be systematic and evaluate the vessels, the aerodigestive tract, the spinal cord, the nerves, and the lungs:

1. Vascular structures: "Hard" signs and symptoms highly diagnostic of vascular trauma include active bleeding, shock not explained by other injuries, expanding or pulsatile hematoma, absent or significantly diminished peripheral pulses, and bruit. "Soft" signs and symptoms suggestive but not diagnostic of vascular trauma include mild shock, stable hematoma, and slow bleeding. Only about 2% of patients with soft signs have significant vascular injuries requiring intervention. The presence of a seat-belt mark in the neck is a suspicious sign of associated vascular trauma. Unexplained neurological findings (coma, hemiplegia) may be due to a vascular injury. This group of patients requires CTA to evaluate the neck vessels.
2. Aerodigestive tract: Hard signs or symptoms highly diagnostic of significant laryngotracheal trauma include respiratory distress, air bubbling through a neck wound, and massive hemoptysis. There are no hard signs diagnostic of esophageal trauma. Soft signs and symptoms suspicious of aerodigestive trauma include subcutaneous emphysema, hoarseness, odynophagia, and minor hemoptysis. Only about 15% of these patients have significant aerodigestive injuries.
3. Nervous system: The examination should include GCS, localizing signs, pupils, cranial nerves (VII, IX–XII), spinal cord, brachial plexus (median, ulnar, radial, axillary, musculocutaneous nerves), the phrenic nerve, and the sympathetic chain (Horner's syndrome). Many patients with neck trauma have associated head injuries and abnormal neurological examination; therefore, a meticulous examination is necessary to account for all potential injuries. Also, in injuries to the carotid or vertebral arteries, the patient may present with neurological signs, such as low GCS or hemiplegia.

Investigations in Neck Trauma

Unstable patients with hard signs of major vascular or laryngotracheal injuries should forgo further investigation and be taken directly to the operating room. CT scan and angiographic investigations should be considered only in stable patients. Selected patients with hard signs of vascular trauma that are stable or respond to initial resuscitation may benefit from CTA or formal angiography to determine if the lesion is a candidate for stenting or embolization, if this capability is readily available at the institution.

1. Plain chest and neck films can diagnose foreign body, fracture, pneumothorax, subcutaneous emphysema, and, in some cases, hematoma.
2. CT scan of the neck is the most valuable investigation in both blunt and penetrating trauma.
3. CTA is the investigation of choice in suspected vascular injury. In addition, after GSW, it can reliably identify a bullet tract, allowing the provider to have a more specific understanding of the potentially injured structures and thus narrow the need for additional investigations.
4. Diagnostic catheter angiography should be reserved only for cases with shotgun injuries and multiple pellets, or

when the CTA is not conclusive. However, it has a definitive therapeutic role for embolization of a bleeding vessel or endovascular stenting of an injured vessel, false aneurysm, or an arteriovenous fistula.

5. Color flow doppler is noninvasive, accurate, and cost-effective. In addition, it does not require additional intravenous contrast if the patient has already received contrast for other investigations. The combination of a good physical examination and color flow doppler can detect or highly suspect most vascular injuries, including minor ones. Limitations include visualization of the proximal left subclavian artery in obese patients, the internal carotid artery near the base of the skull, and parts of the vertebral artery under the bony part of the vertebral canal.
6. Esophagogram should be considered in patients sustaining penetrating trauma with subcutaneous emphysema, odynophagia, or hematemesis, especially if the CT shows a wound tract near the esophagus. Very often it is supplemented by esophagoscopy. The sensitivity of the esophagogram is best for evaluation of the thoracic esophagus and less well suited for the high cervical esophagus.
7. Esophagoscopy and laryngoscopy/tracheoscopy are indicated in patients with suspicious findings, such as subcutaneous emphysema, or a wound tract near the esophagus or trachea.

General Management

In an urban environment, the “scoop and run” principle should be applied in penetrating neck injuries. Any external bleeding should be controlled by direct pressure. Protective cervical spine collars should be applied loosely and with caution because of the risk of airway obstruction in patients with large neck hematomas. Cervical spine immobilization is not necessary in knife injuries, and though gunshot wounds to the spine can cause fractures, in neurologically intact patients, they rarely are unstable.

Airway compromise may occur because of an external compressing hematoma, a laryngotracheal hematoma, or a major open wound of the larynx or trachea. Orotracheal intubation can be a difficult and potentially dangerous task in the prehospital environment and should not be undertaken lightly.

The initial assessment in the emergency department should always follow ATLS guidelines. Approximately 10% of penetrating neck injuries present with airway compromise. Endotracheal intubation should be attempted only in the presence of a surgeon who can perform a cricothyroidotomy, in case of intubation failure. In fairly stable patients with airway compromise, fiberoptic nasotracheal intubation should be attempted first. For attempted orotracheal intubation, muscle relaxants should be used only in selected cases and by physicians with significant intubation experience, because of the risk of airway loss. On the other hand, intubation without pharmacological paralysis may aggravate bleeding and airway obstruction due to patient coughing and straining, and thus the optimal method of airway establishment should be individualized.

Any external bleeding is controlled by direct pressure or by balloon tamponade using a Foley catheter. In order to avoid air embolism, patients with suspected venous injuries should be put in the Trendelenburg position. Intravenous lines should be avoided on the same side as the injury because of the possibility of a proximal venous injury.

Patients arriving in the emergency department with cardiac arrest should have an emergency department thoracotomy performed. As part of the resuscitation efforts, inspect coronary veins for air embolism and if air bubbles are seen, the right ventricle of the heart should be aspirated.

Following a careful initial physical examination and appropriate investigations, a decision should be made about operation or observation. The selection of the type of management can safely be made on the basis of a good clinical examination and appropriate investigations.

Tips and Pitfalls

- Do not attempt pharmacological paralysis for emergency endotracheal intubation in the presence of a large neck hematoma without being ready or having the skills for a cricothyroidotomy. If the vocal cords cannot be visualized, the loss of airway may be catastrophic!
- Do not insert a nasogastric tube in an awake patient in the presence of a large neck hematoma or suspected vascular injury. Straining and coughing may precipitate bleeding. If a nasogastric tube is needed, wait until the patient is anesthetized.
- Do not insert an intravenous line in the arm on the same side as the neck injury. Any infused fluids may be extravasated from a more central injury. Always use the opposite side.
- It is recommended to perform a clinical examination according to a written protocol. The inexperienced physician can easily miss important signs and symptoms or neck trauma.
- Consider neck vascular injuries (carotid or vertebral artery) in patients with unexplained neurological findings.

Penetrating Neck Injuries

Anatomical Zones of the Neck

The description of penetrating neck injuries according to zones is useful in the evaluation and management of the patient. The incidence of significant injuries with zone I wounds is about 15%; in zone II, 25%; and in zone III, 25%. About 15% of patients with zone I or II injuries, and 5% with zone III injuries, require surgical intervention. Also, vascular evaluation in zones I and III is more difficult than in zone II. The vessels in these areas are not easily accessible to color flow doppler studies, and CT angiographic evaluation is the investigation of choice. It is important to remember, however, that the trajectory of the penetrating wound cannot be determined based on the zone of entry, and injuries can often traverse multiple zones, despite the presence of a small entry wound (Figure 3.1, Figure 3.2 A,B, Figure 3.3 A,B, Figure 3.4 A,B).

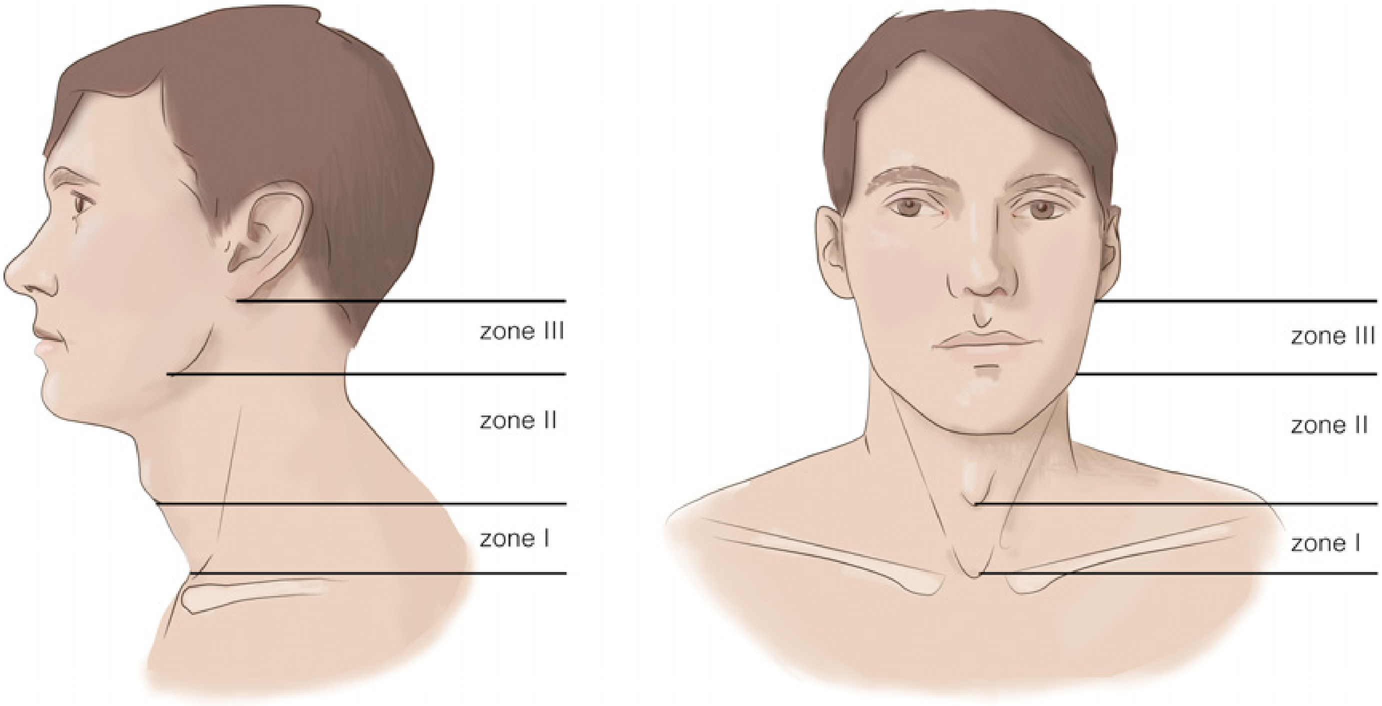

zone III
zone II
zone I
zone III
zone II
zone I

Figure 3.1 Anatomical zones of the neck. Zone I is confined between the clavicle and the cricoid cartilage, zone II between the cricoid and the angle of the mandible, and zone III between the angle of the mandible and the base of the skull.

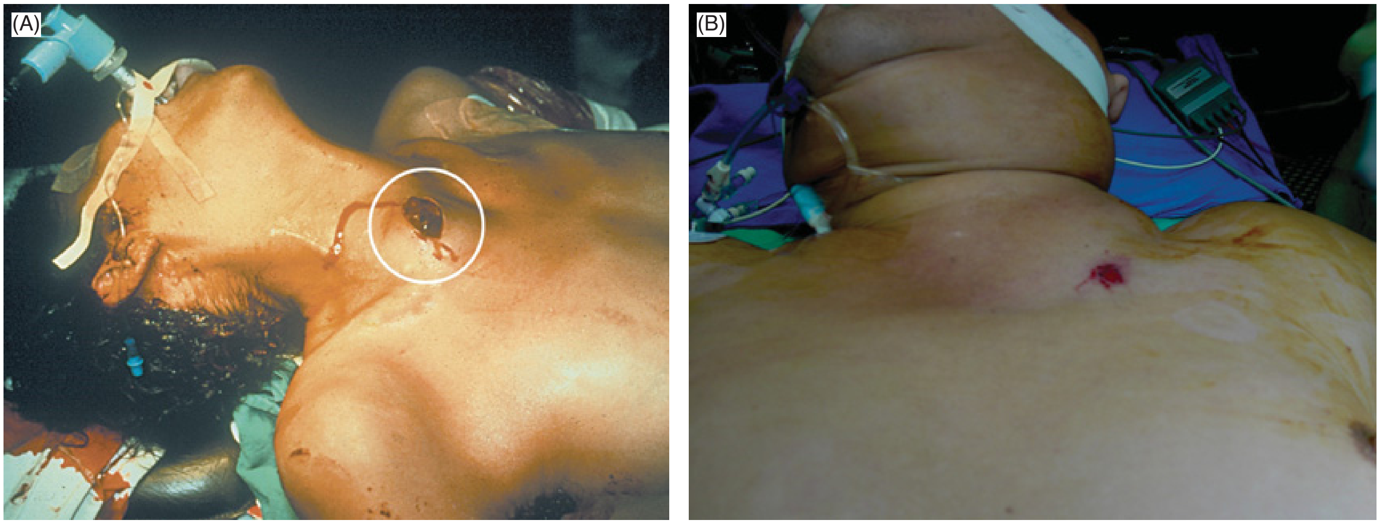


Figure 3.2 A,B Zone I penetrating injuries. Stab wound (A). Gunshot wound, associated with large hematoma (B).

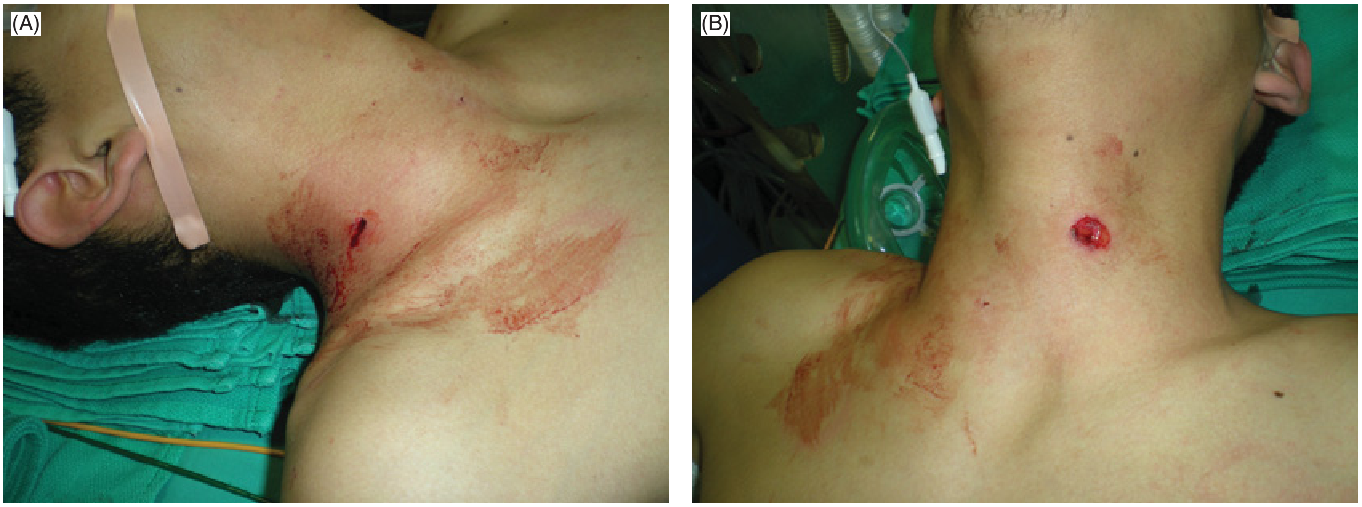


Figure 3.3 A,B Zone II penetrating injuries. Knife wound (A). Gunshot wound (B).

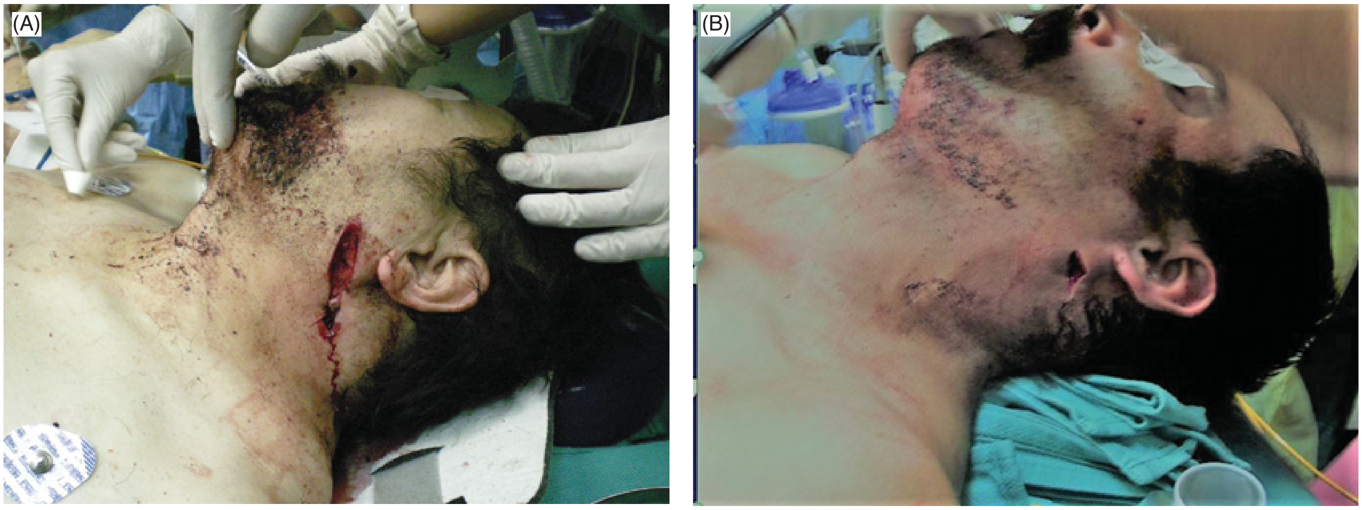


Figure 3.4 A,B Patients with zone III stab wound to the neck.

Epidemiology of Penetrating Neck Trauma

Overall, about 35% of all gunshot wounds and 20% of stab wounds to the neck result in significant injuries to vital structures. Transcervical gunshot wounds are associated with the highest incidence (75%) of significant injuries. The most commonly injured structures are the vessels (about 20% of patients), followed by the spinal cord, aerodigestive tract, and nerves (about 5–10% each).

Overall, only about 20% of gunshot wounds and 10% of stab wounds require operation. Some patients with significant vascular injuries may be managed with angiointervention. The remaining patients can be managed nonoperatively.

Physical Examination of Penetrating Injuries of the Neck

Physical examination is very reliable in diagnosing or highly suspecting significant injuries requiring surgical intervention. In order to avoid missing significant signs or symptoms, it is strongly recommended to perform the examination according to a written protocol.

Asymptomatic patients are highly unlikely to have any significant trauma requiring surgical treatment. Depending on the findings of clinical examination, a CTA or color flow doppler may be indicated (Table 3.1, Figure 3.5).

Table 3.1 Physical examination protocol for penetrating injuries of the neck

A. URGENT PRIORITIES			
☐ Control any active bleeding (pressure, packing, Foley's catheter)			
☐ If active bleeding: Trendelenburg position to prevent air embolism			
☐ Secure airway			
☐ IV fluids (in zone I injuries, no IV line on the side of the injury)			
B. SYSTEMIC EXAMINATION			
☐ Dyspnea	☐ yes	☐ no	
☐ Blood pressure			
☐ Pulse			
☐ Color	☐ pale	☐ normal	
C. LOCAL EXAMINATION			
Vascular structures			
☐ Active bleeding	☐ minor	☐ severe	☐ no
☐ Expanding hematoma	☐ small	☐ large	☐ no
☐ Pulsatile hematoma	☐ yes	☐ no	
☐ Peripheral pulses (compare with normal side,doppler?)	☐ normal	☐ diminished	☐ absent
☐ Bruit	☐ yes	☐ no	
D. LARYNX – TRACHEA – ESOPHAGUS			
☐ Hemoptysis	☐ yes	☐ no	
☐ Air bubbling through wound (ask patient to cough)	☐ yes	☐ no	
☐ Subcutaneous emphysema	☐ yes	☐ no	
☐ Pain on swallowing sputum	☐ yes	☐ no	
E. NERVOUS SYSTEM			
☐ Glasgow Coma Scale			
☐ Localizing Signs			
☐ Cranial nerves			
Facial nerve	☐ yes	☐ no	
Glossopharyngeal nerve	☐ yes	☐ no	
Recurrent laryngeal nerve	☐ yes	☐ no	
Accessory nerve	☐ yes	☐ no	
☐ Spinal cord			
☐ Brachial plexus injury	☐ normal	☐ abnormal	
Median nerve	☐ yes	☐ no	
Ulnar nerve	☐ yes	☐ no	
Radial nerve	☐ yes	☐ no	
Musculocutaneous nerve	☐ yes	☐ no	
Axillary nerve	☐ yes	☐ no	
Homer's syndrome	☐ yes	☐ no	
F. INVESTIGATIONS (only in fairly stable patients) Chest X-ray (erect)			
☐ Hemopneumothorax			
☐ Subcutaneous emphysema			
☐ Widened upper mediastinum			
☐ Retained knife blade or missile			

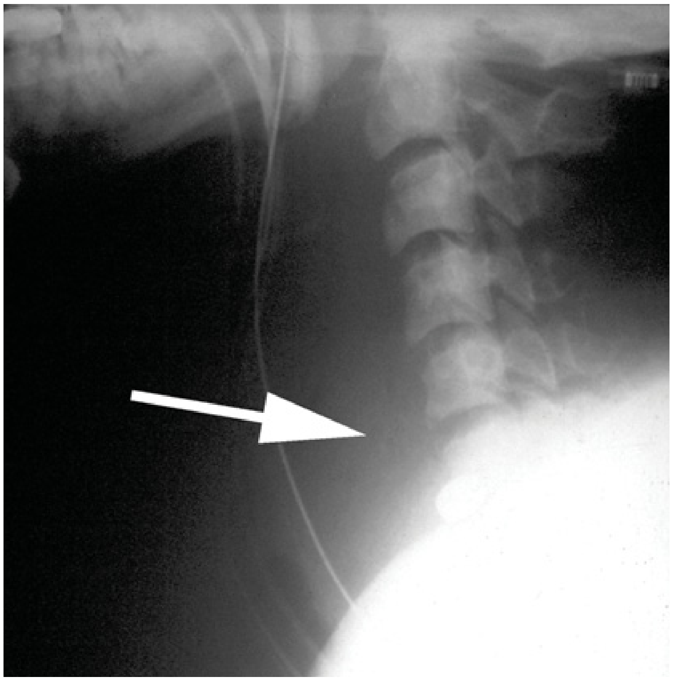


Figure 3.7 Lateral neck X-ray, in a patient with a gunshot wound, shows a large prevertebral hematoma (arrow).

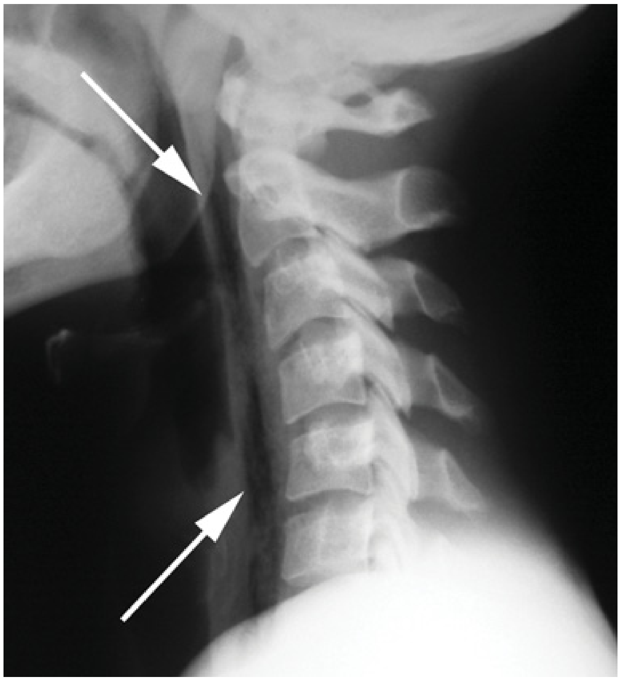


Figure 3.8 Lateral neck X-ray in a patient with a knife wound to neck shows prevertebral air (arrows). This finding is highly suspicious of aerodigestive trauma.

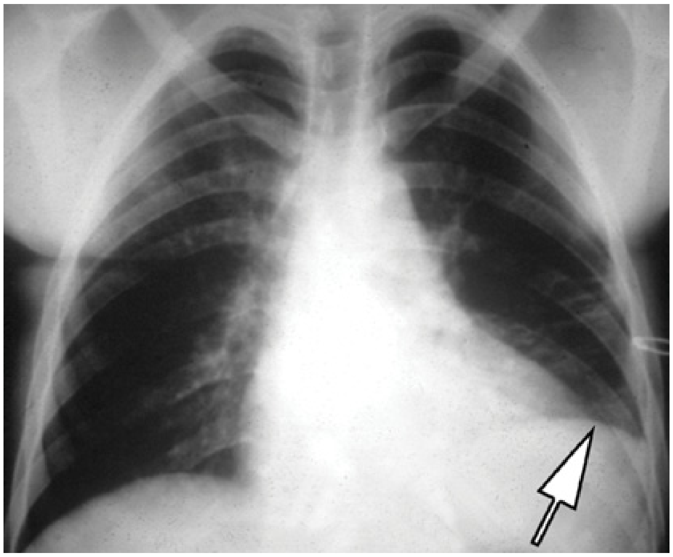


Figure 3.9 Patient with a stab wound to the neck. Chest X-ray showing elevated left hemidiaphragm (arrow) secondary to phrenic nerve injury.

CT Scan in Penetrating Neck Trauma

The CT may provide information about the site and nature of any fracture, involvement of the spinal cord, the presence of fragments in the spinal canal, the presence of any hematomas compressing the cord, vascular injuries including pseudoaneurysms, dissections, thrombosis, or extravasation, and/or subcutaneous emphysema, indicating aerodigestive injury. In addition, the direction of the bullet tract may help the physician determine the need for further diagnostic studies including esophagogram or endoscopy.

A CTA should be a routine investigation in all hemodynamically stable patients with penetrating neck trauma. A CTA should be performed in all patients with penetrating neck trauma and unexplained neurological deficits. It may identify an anemic infarct or brain edema secondary to a carotid artery injury (Figure 3.10 A–D, Figure 3.11, Figure 3.12).

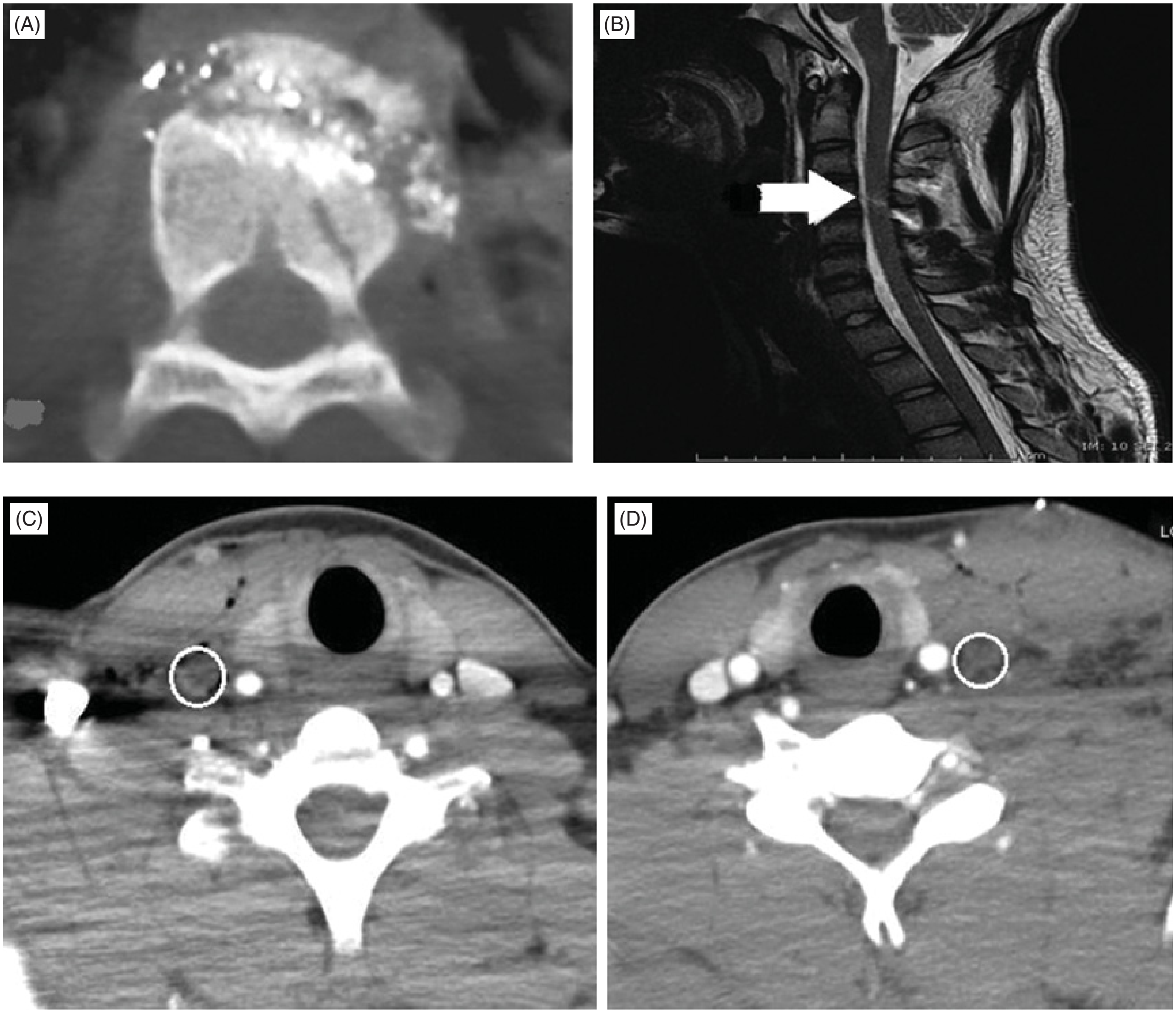


Figure 3.10 A–D Transcervical gunshot wound: CT scan shows a fracture of the vertebral body (A). Patient with a stab wound to the neck, complaining of left-sided weakness in his arm and legs. MRI shows hemi-transection of the spinal cord (arrow) (B). CT angio of a patient with a gunshot wound to the neck shows occlusion of the right internal jugular vein (circle; C). Patient with a gunshot wound to the left neck and a large neck hematoma. CT angio shows occlusion of the left internal jugular vein (circle; D).

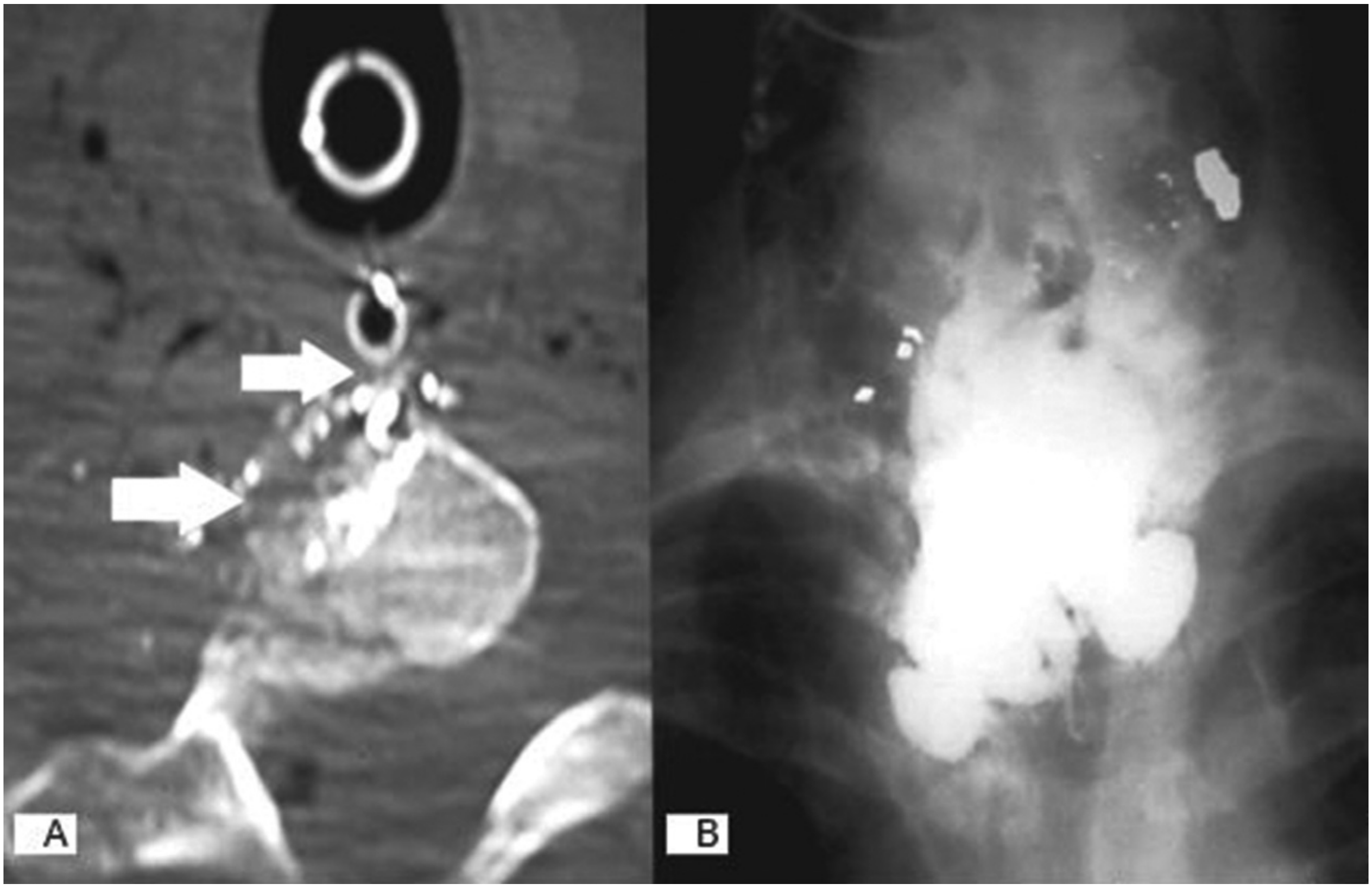


Figure 3.11 A,B CT scan shows a gunshot wound tract to be near the esophagus (arrows; A). A contrast swallow study shows an esophageal injury with contrast extravasation (B).

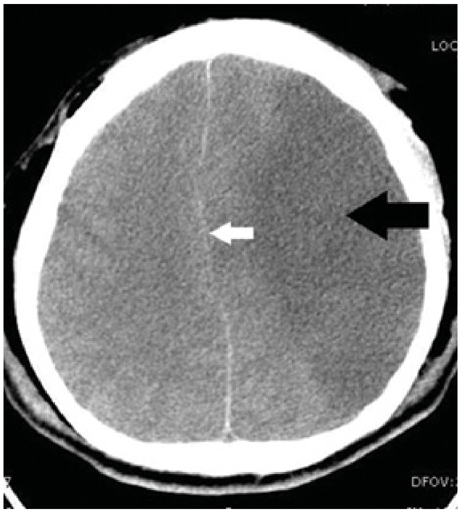


Figure 3.12 Patient involved in a motor vehicle accident with a seat-belt mark on the neck and in coma. The CT scan shows a massive anemic infarction of the left hemisphere (large arrow), brain edema, and midline shift (small arrow).

Evaluation of Vascular Structures

Asymptomatic patients are highly unlikely to have significant vascular injuries requiring surgical intervention or angiographic embolization. However, in about 8% of asymptomatic patients investigated by angiography, there is a vascular injury not requiring any type of treatment. Patients with soft signs of vascular trauma need evaluation either by CTA or color flow doppler. In zone I injuries, the presence of a peripheral pulse does not preclude a significant subclavian or axillary arterial injury (Figure 3.13 A,B).

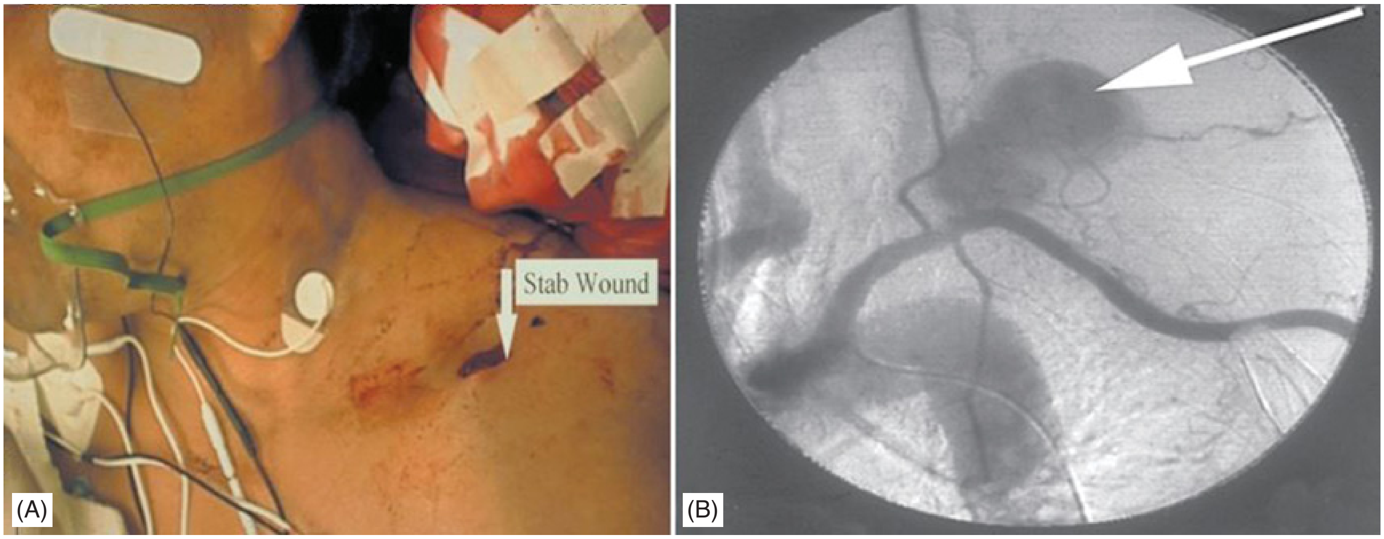


Figure 3.13 A,B Zone I injury with vascular trauma. Stab wound to zone I of the neck (arrow). The patient has peripheral pulse present in his left arm (A). Angiogram showing pseudoaneurysm (arrow) of the left subclavian artery (B).

It is essential that the pulse on the affected side is compared to the contralateral side. An objective measurement is the brachial–brachial index (BBI). The BBI is measured by taking the systolic pressure of the arm on the injured side and comparing it to the systolic pressure of the arm on the uninjured side. An index >0.90 is unlikely to be associated with significant arterial injury. It is recommended that all asymptomatic zone I penetrating injuries be evaluated routinely by BBI and either CTA or color flow doppler.

Color Flow Doppler

In the appropriate setting, color flow doppler may be a useful investigation for suspected vascular trauma in most patients who are hemodynamically stable. However, it may not be immediately available, and it is operator-dependent. Color flow doppler has some limitations in the visualization of the internal carotid artery near the base of the skull, sections of the vertebral artery directly underneath the bony part of the vertebral canal, and the proximal subclavian vessels, especially on the left side and in obese patients (Figure 3.14).

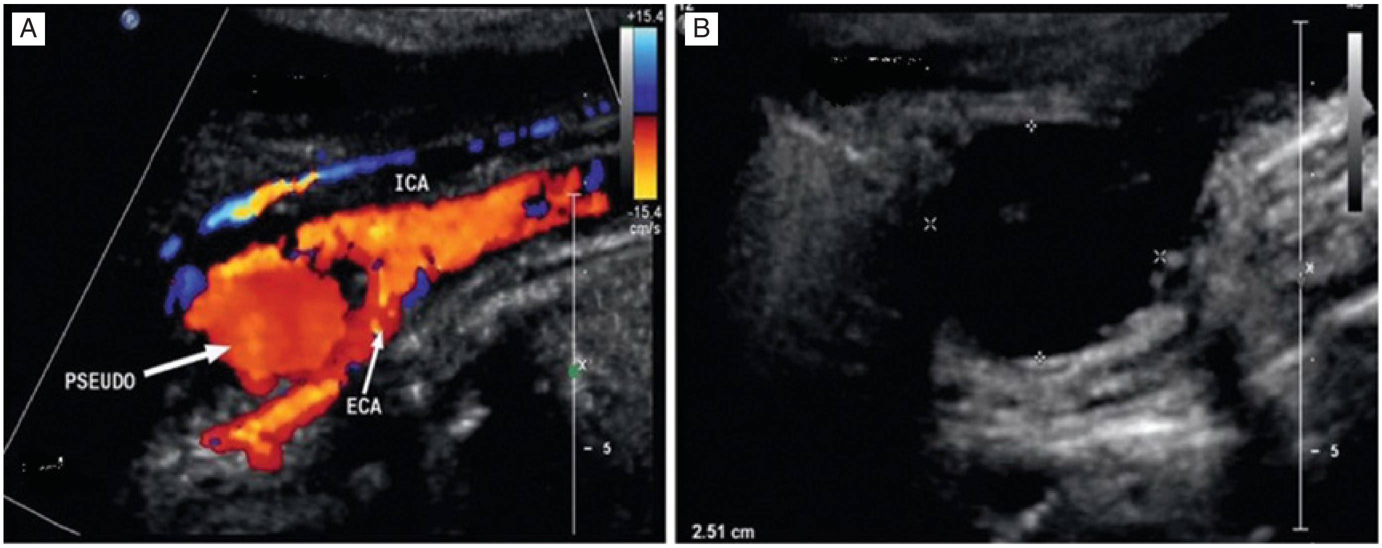


Figure 3.14 Color flow doppler showing pseudoaneurysm of the internal carotid, following penetrating trauma (left). Color flow Doppler evaluates the flow, and the grayscale duplex demonstrates the pseudoaneurysm between the stars (right).

Angiography for Penetrating Injuries

Catheter-based angiography can be used for diagnostic or therapeutic purposes in penetrating neck trauma. When compared to CT scan, it has the diagnostic advantage to digitally subtract any interfering objects. This is particularly useful in evaluating vasculature after shotgun injuries or injuries in which retained a foreign body can cause artifact on CT imaging. However, with the high sensitivity and specificity of the CT scan and the ease in obtaining it, angiography is now used mostly for therapeutic interventions after diagnosis of vascular injuries.

Diagnostic indications include (a) shotgun injuries with multiple pellets, (b) foreign bodies resulting in poor quality CT scan images, and (c) embedded foreign body, such as a knife blade, before removal. Therapeutic indications for stenting or embolization include (a) bruit, (b) continuous bleeding following a gunshot wound to the face, and (c) CTA diagnosis of false aneurysm or arteriovenous fistula (Figure 3.15 A–C, Figure 3.16 A,B, Figure 3.17 A,B).

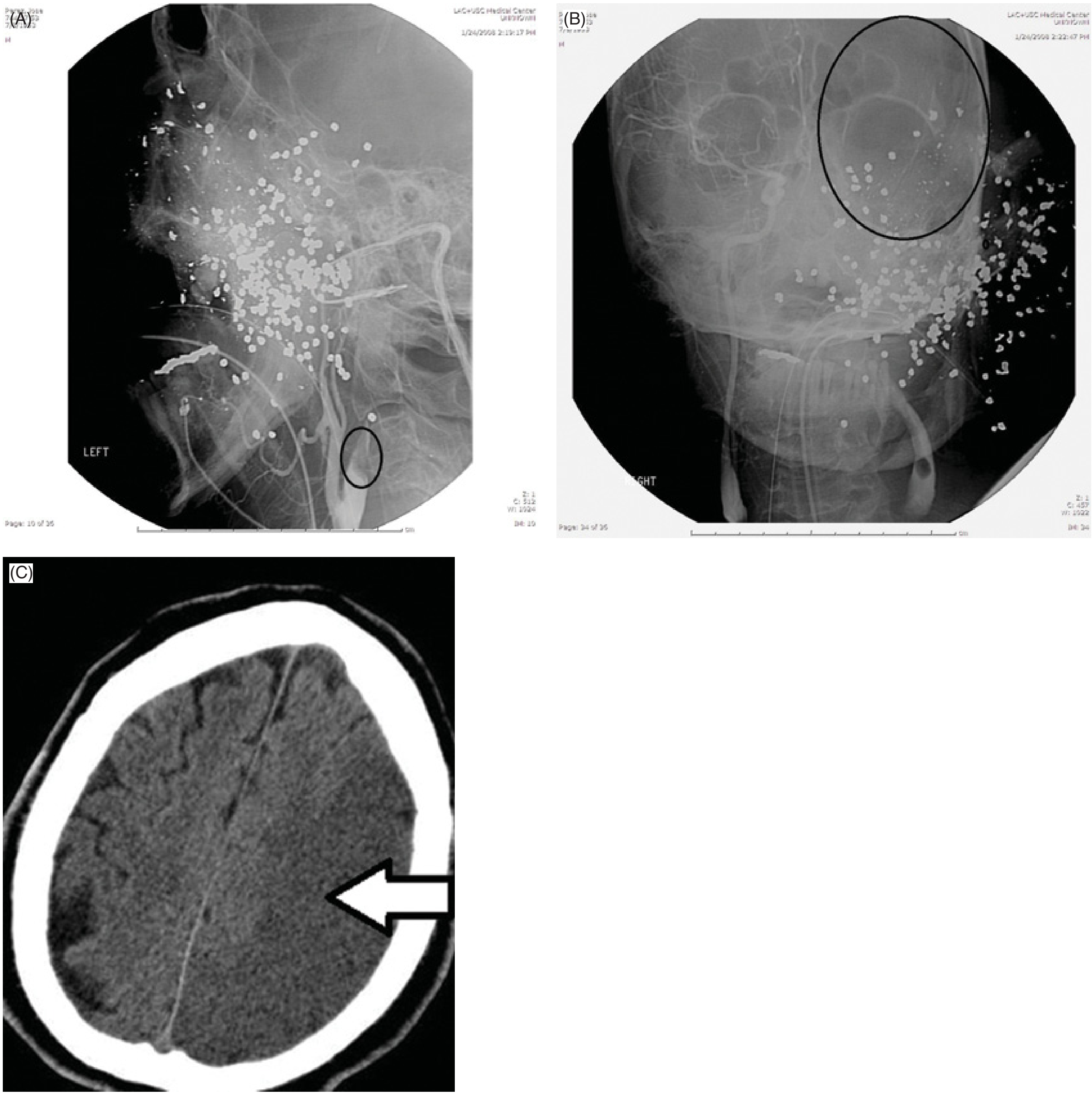

(A)
LAC+USC Medical Center
LEFT
(B)
LAC+USC Medical Center
GHT
(C)

Figure 3.15 A–C Patient with shotgun injury in the face and neck admitted in coma. An angiogram showing a complete occlusion of the left internal carotid artery (circle; A). Angio of the normal right carotid showing poor collateral circulation to the left brain (circle; B). CT scan showing a large anemic infarction (arrow) of the left brain (C).

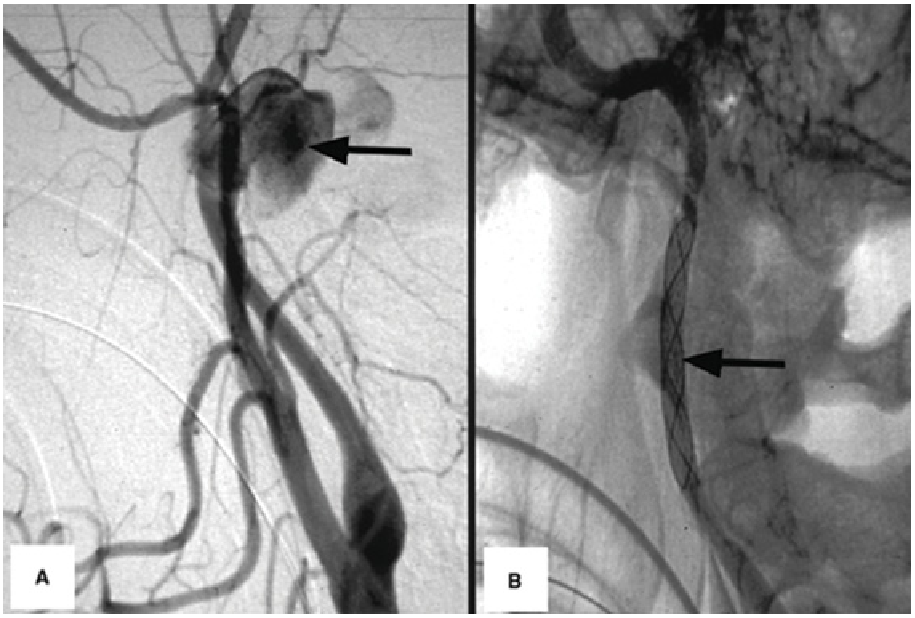


Figure 3.16 A,B Penetrating trauma to zone III of the neck. Angiography showing and false aneurysm of the distal internal carotid artery (arrow; A). The patient was successfully managed with an endovascularly placed stent-graft (B).

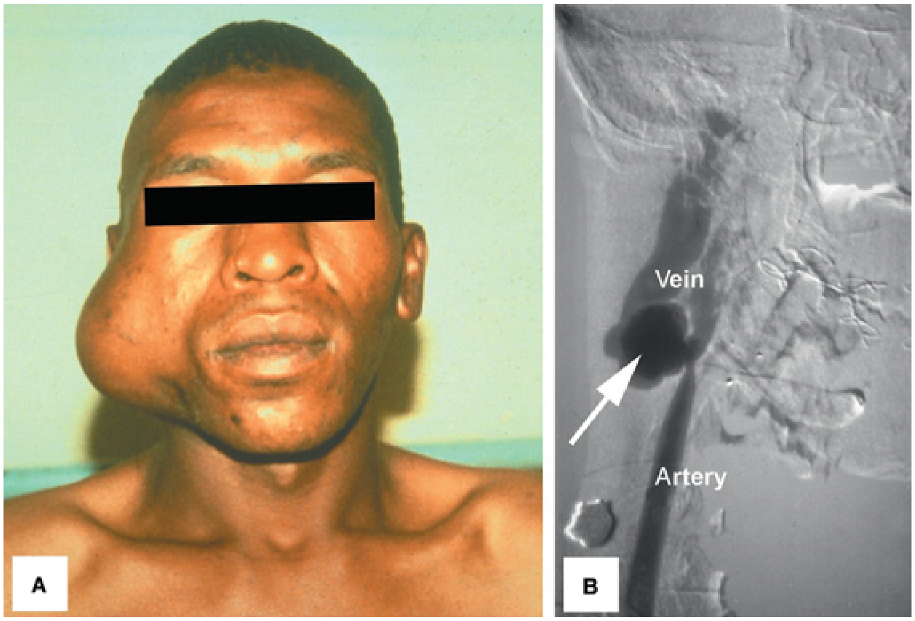


Figure 3.17 A,B Patient with stab wound to zone III of the neck presenting a few weeks after the injury with a pulsating mass and constant noise in his right ear. Physical exam found a pulsatile mass with a bruit (A). Angiogram shows a pseudoaneurysm (arrow) of the internal carotid artery and communication with the internal jugular vein (B). The patient was successfully managed with an endovascular stent-graft.

Evaluation of the Aerodigestive Tract

Asymptomatic patients are highly unlikely to have a significant injury requiring surgical management. Unevaluable patients or patients with soft symptoms of aerodigestive injuries need investigation via a CT scan of the neck and, in the appropriate cases, by endoscopy and/or contrast swallow studies.

The esophagus is evaluated by means of esophagography or endoscopy. The combination of the two investigations has a sensitivity of 100%. Rigid esophagoscopy is superior to flexible esophagoscopy in evaluating the upper esophagus; however, rigid endoscopy can be performed only under general anesthesia. Thus this investigation is best reserved for patients undergoing anesthesia for another reason.

Patients with hard signs diagnostic of laryngotracheal injuries need an emergency operation without any special investigations. However, patients with soft signs require evaluation by means of endoscopy (Table 3.3, Figure 3.18 A,B, Figure 3.19, Figure 3.20 A,B, Figure 3.21 A,B, Figure 3.22 A–D).

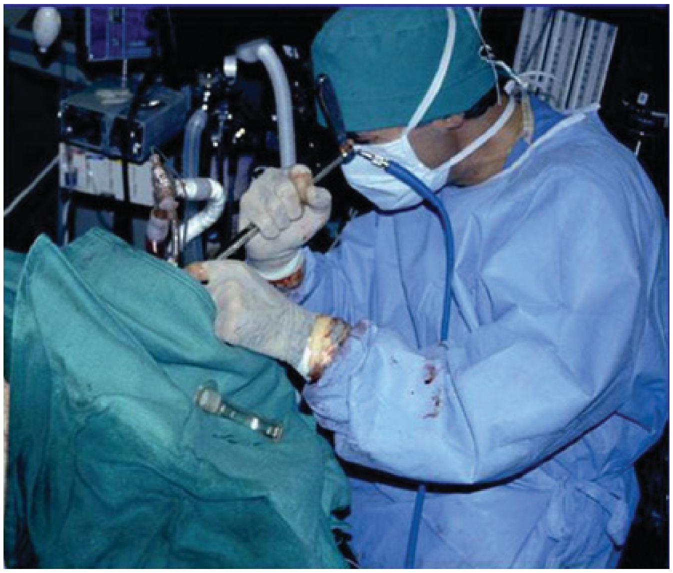


Figure 3.19 Rigid esophagoscopy is a reliable investigation in the evaluation of the cervical esophagus, but it can be performed only under general anesthesia in the operating room.

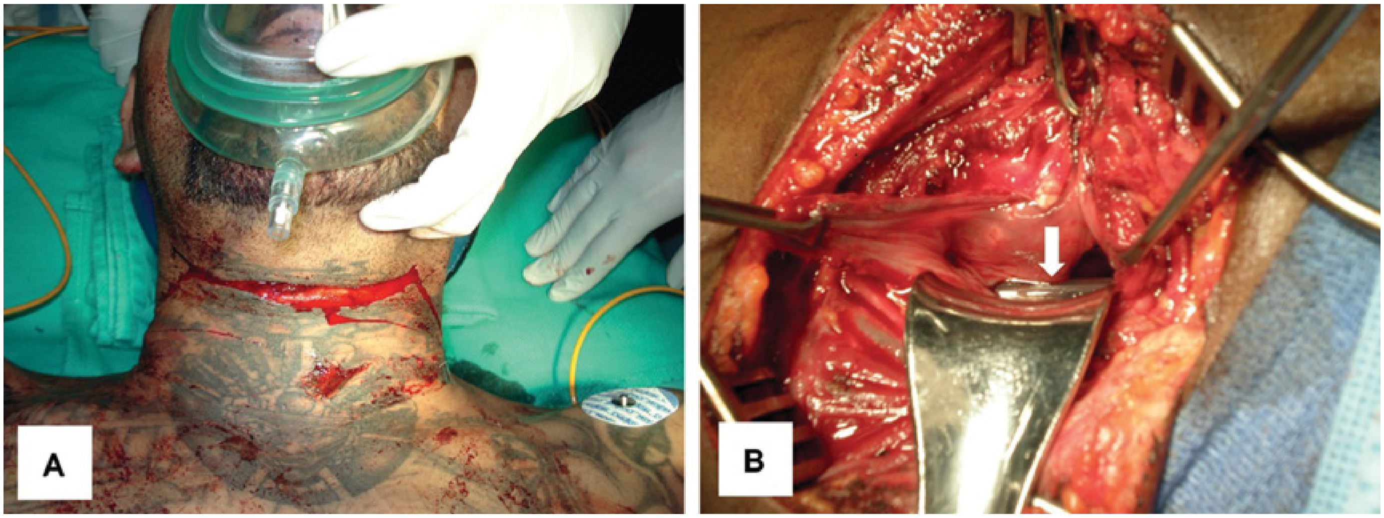


Figure 3.20 A,B Patient with a stab wound to the neck in zone II, presenting with hematemesis (A). Operative exploration showing a large laceration in the pharynx exposing the nasogastric tube (arrow; B).

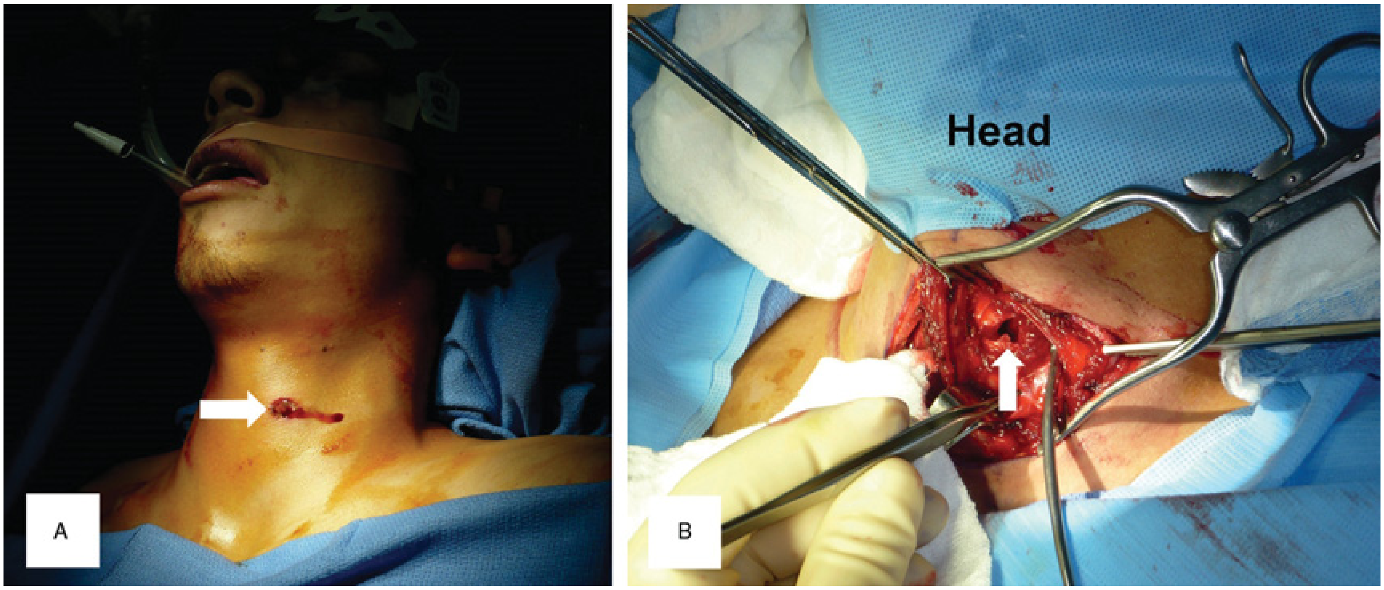


Figure 3.21 A,B Patient with a zone II gunshot wound presenting with hemoptysis and air bubbling through the wound (A). He was taken to the operating room without any diagnostic tests. Exploration shows an injury to the trachea (arrow; B).

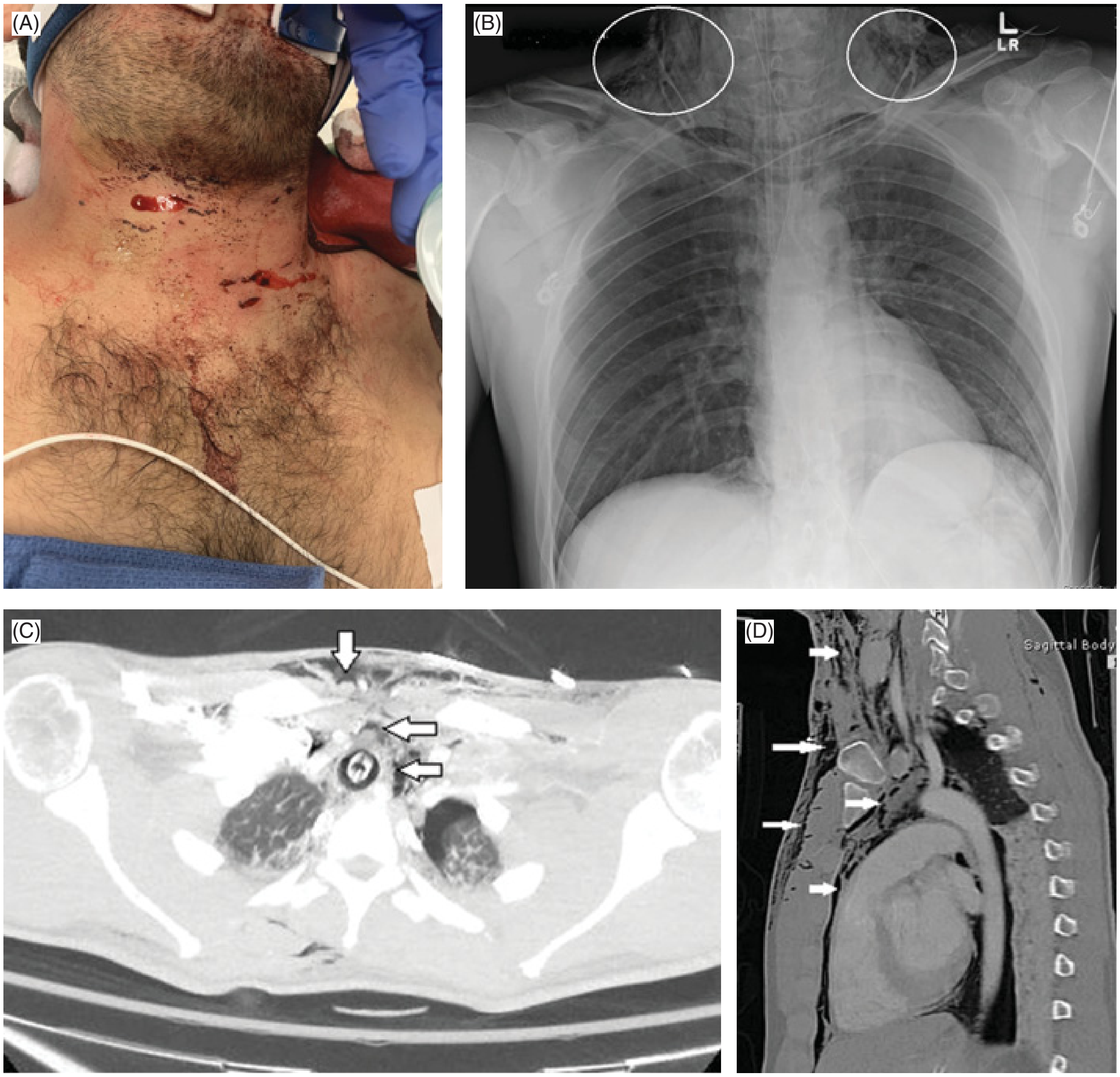


Figure 3.22 A–D Patient with dog bites in the neck presenting with respiratory distress, hemoptysis, and extensive neck and anterior chest emphysema (A). Chest X-ray showing extensive neck emphysema (B). CT scan showing subcutaneous emphysema in the neck and anterior chest wall and mediastinum (C, D). Upon operation, there was an injury to the trachea.

Establishing an Airway in the Presence of a Neck Hematoma

Establishing an airway in the emergency department or the operating room in the presence of a large neck hematoma can be a difficult and potentially dangerous procedure. Pharmacological paralysis for endotracheal intubation should always be performed in the presence of an experienced physician ready to perform a cricothyroidotomy, especially if the vocal cords cannot be visualized and the patient cannot be bag-valve mask ventilated.

The best approach is fiberoptic nasotracheal intubation under light sedation, provided that the patient is not hypoxic and can cooperate. It must be remembered that in the presence of a large neck hematoma, a cricothyroidotomy may be a difficult and bloody procedure (Figure 3.23 A,B, Figure 3.24, Figure 3.25, Figure 3.26).

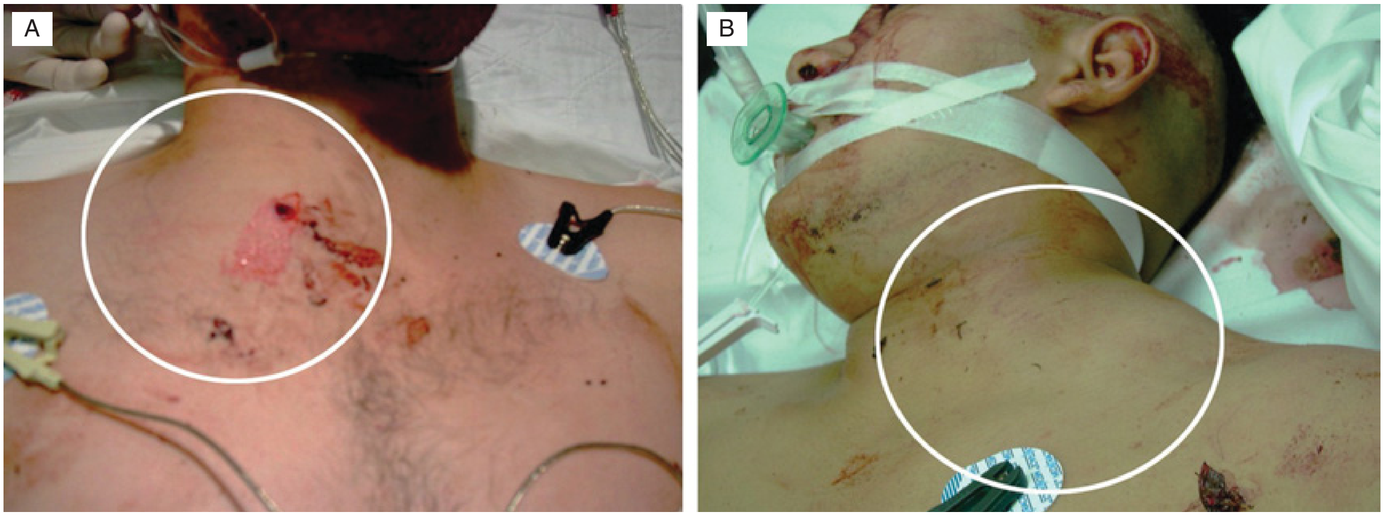


Figure 3.23 A,B Patients with large neck hematomas may pose significant airway challenges and require early intubation. The decision on the technique of airway establishment should be based on the condition of the patient and the experience of the physicians.

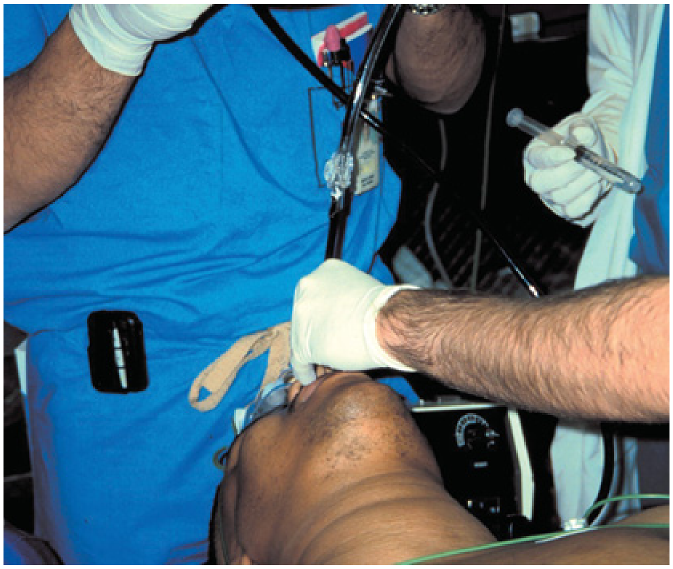


Figure 3.24 Awake, fiberoptic intubation of a patient with a large neck hematoma from a gunshot wound. This approach should be considered in fairly stable patients without severe respiratory distress.

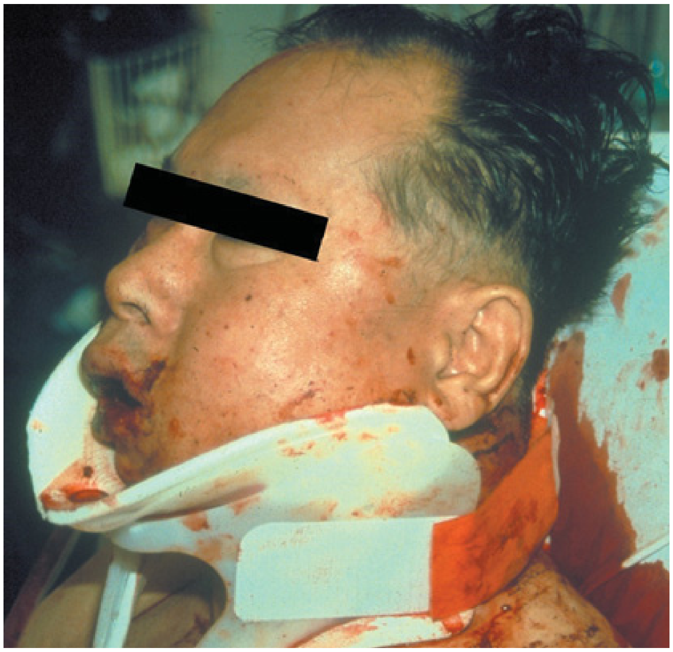


Figure 3.25 Patient with a large neck hematoma following penetrating trauma. Application of a tight cervical collar may aggravate the airway obstruction.

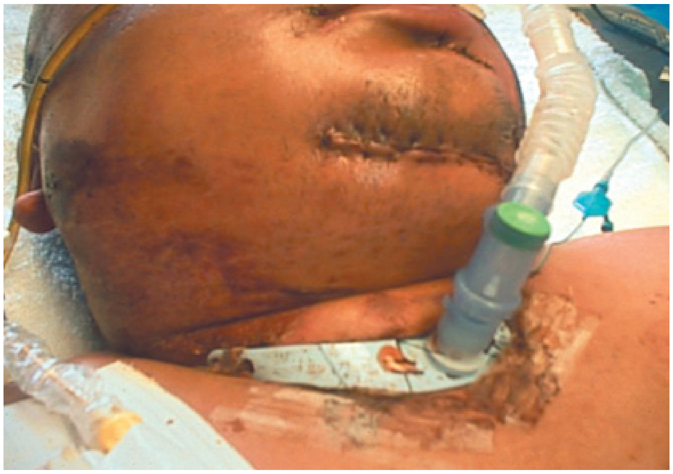


Figure 3.26 Patient who required an emergency cricothyroidotomy following failed endotracheal intubation due to a large neck hematoma and airway compromise.

Bleeding Control in the Emergency Department

In most cases, the bleeding may be controlled by direct digital pressure in the wound (Figure 3.27 A,B). However, in some cases, especially in zones I and III, direct pressure is not effective. In these situations, insertion of the tip of a Foley catheter into the wound and inflation of the balloon with sterile saline may control the bleeding (Figure 3.28 A,B, Figure 3.29).

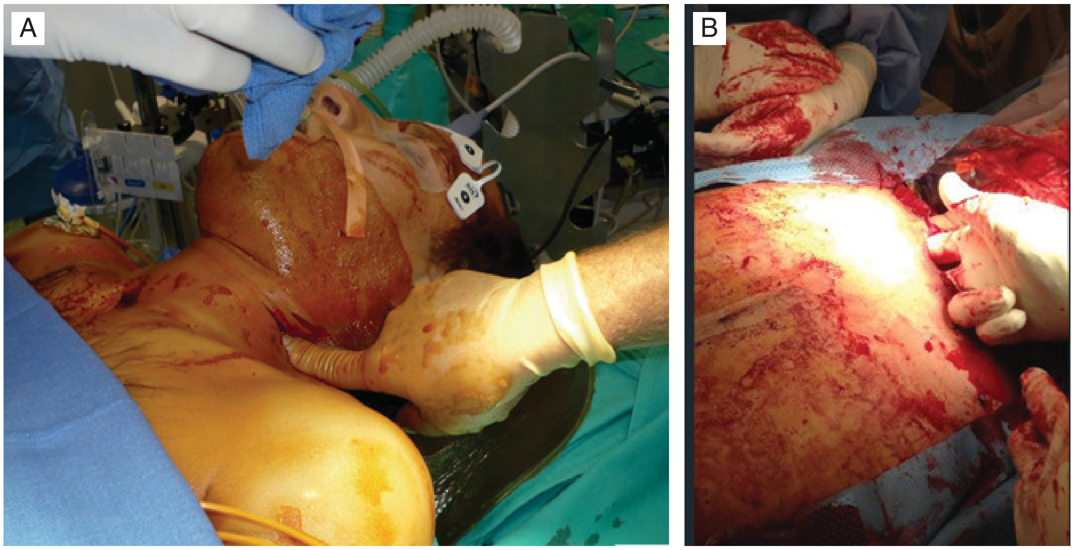


Figure 3.27 A,B Patient with stab wound to zone II of the neck, presenting with severe bleeding due to a carotid artery injury. Finger compression can effectively control the hemorrhage (A). Patient with stab wound to zone I of the neck, presenting with severe bleeding due to a proximal left subclavian artery injury. Finger compression with effective control of the hemorrhage (B).

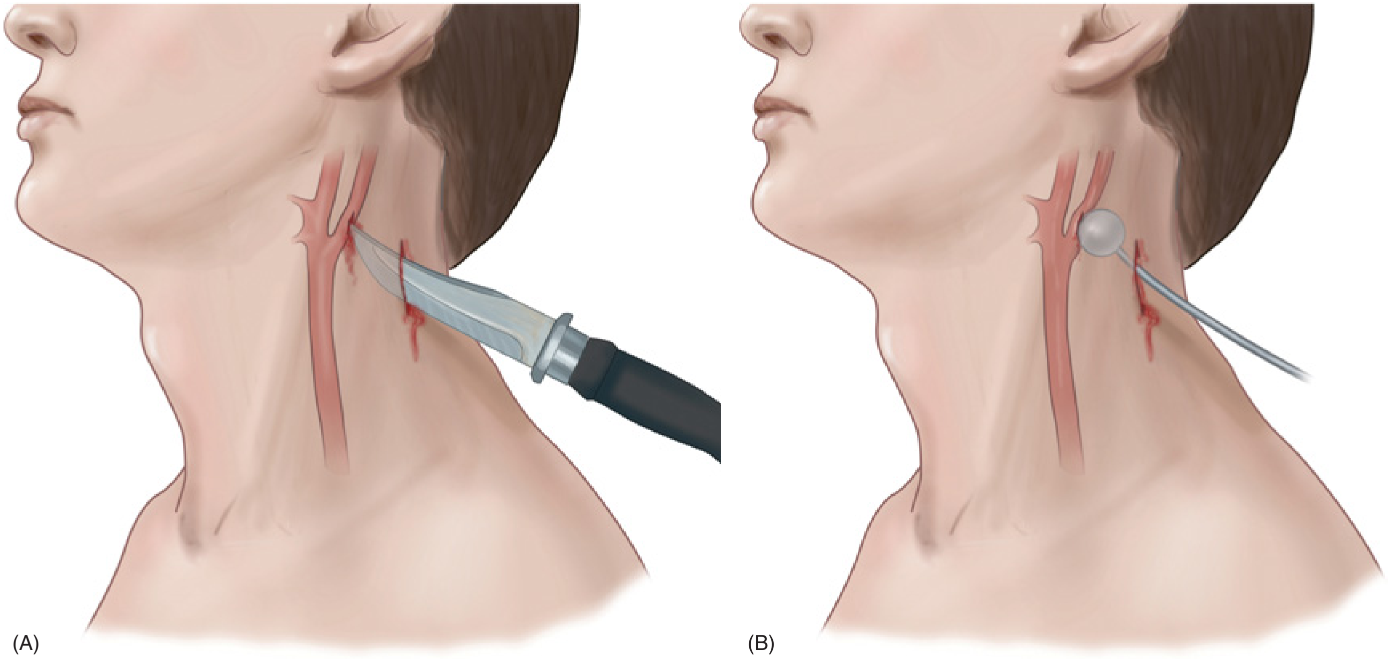


Figure 3.28 A,B Concept of Foley catheter balloon tamponade of difficult bleeding from the neck.

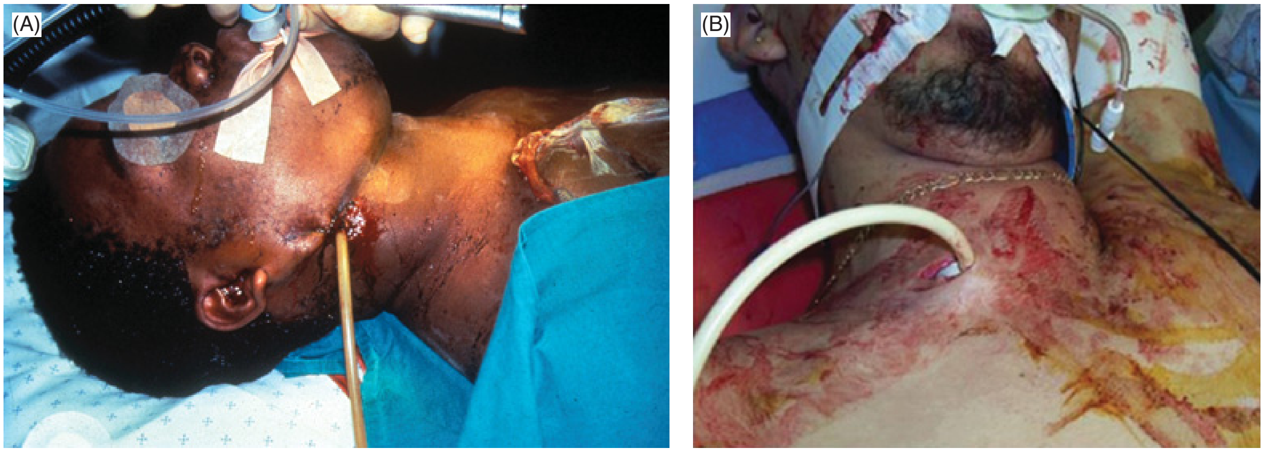


Figure 3.29 Balloon tamponade with a Foley catheter balloon and effective bleeding control in a patient with a zone III stab wound to the neck and bleeding from the internal carotid artery (A). Same procedure in a patient with a stab wound to the zone I and bleeding from a subclavian vessel injury (B).

Some patients with neck vascular injuries arrive in the emergency room with no vital signs or suffer a cardiac arrest soon after admission, usually due to massive blood loss. In these cases, a resuscitative thoracotomy should be performed. The subclavian vessels can be accessed and the bleeding controlled through the thoracotomy, at the apex of the pleural cavity (Figure 3.30).

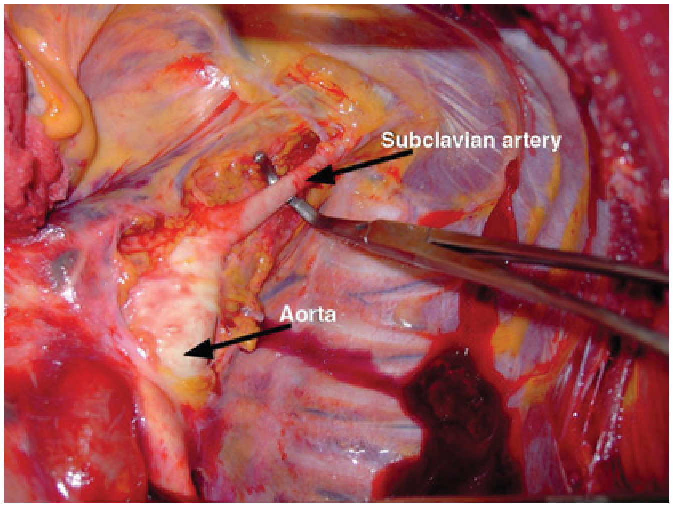


Figure 3.30 Emergency department resuscitative thoracotomy following cardiac arrest due to severe blood loss from a left subclavian artery injury. Subclavian vessel control can be achieved through the chest, at the apex of the pleural cavity.

Foreign Object Impaled in the Neck

Sharp foreign bodies, such as knife blades impaled in the neck, should not be removed without extreme care and preparation. The trace of the object should be evaluated by cross-sectional imaging when possible, and any object with a tract near major vessels should not be removed without the presence of a surgeon and readily available operating room. If there is concern for vascular injury by the foreign object or the patient shows signs of instability or airway compromise, the foreign body removal should occur in the operating room under direct visualization (Figure 3.31 A–C, Figure 3.32 A–C).

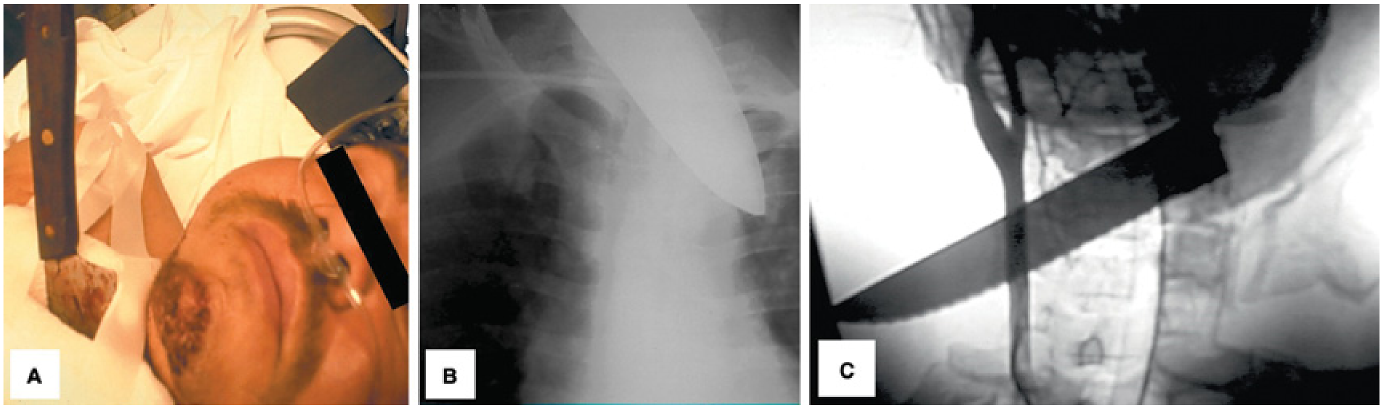


Figure 3.31 A–C Knife embedded in the neck with a suspected tract near vital structures. This should be removed only in the operating room and, in the selected case, after angiography. Patient with a knife embedded in zone I of the neck (A). X-ray showing the knife blade embedded deep in the tissues (B). Angiography revealed no vascular injury, and the knife was removed (C).

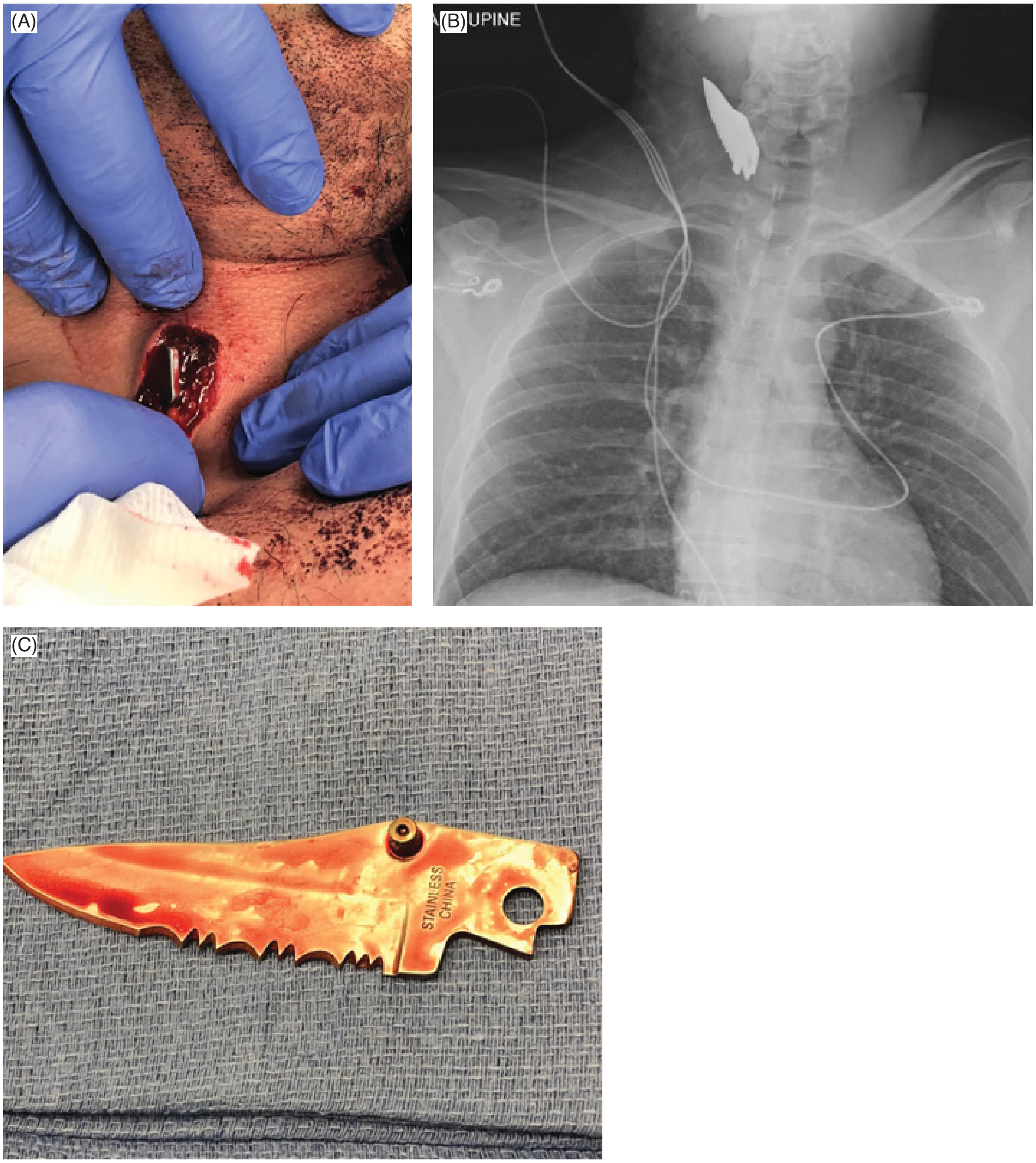


Figure 3.32 A–C Knife blade embedded in the neck (A). X-ray shows a tract away from the mediastinum (B). The blade was removed in the operating room (C) with operative exploration of the vital structures. A pharyngeal injury was found and repaired.

Penetrating Trauma to the Carotid Artery

Carotid artery trauma is diagnosed in about 8% of all penetrating injuries to the neck. Due to close anatomic proximity, there is often associated injury to the internal jugular vein. Bleeding control can temporarily be achieved by digital compression or balloon tamponade, as described previously. Timely operative intervention in cases with active bleeding remains the cornerstone of survival. Patients with false aneurysms, especially in the distal internal carotid artery, which is difficult to access surgically, should be considered for angiointervention and stent-graft placement (Figure 3.33 A–C, Figure 3.34 A,B, Figure 3.35 A–C).

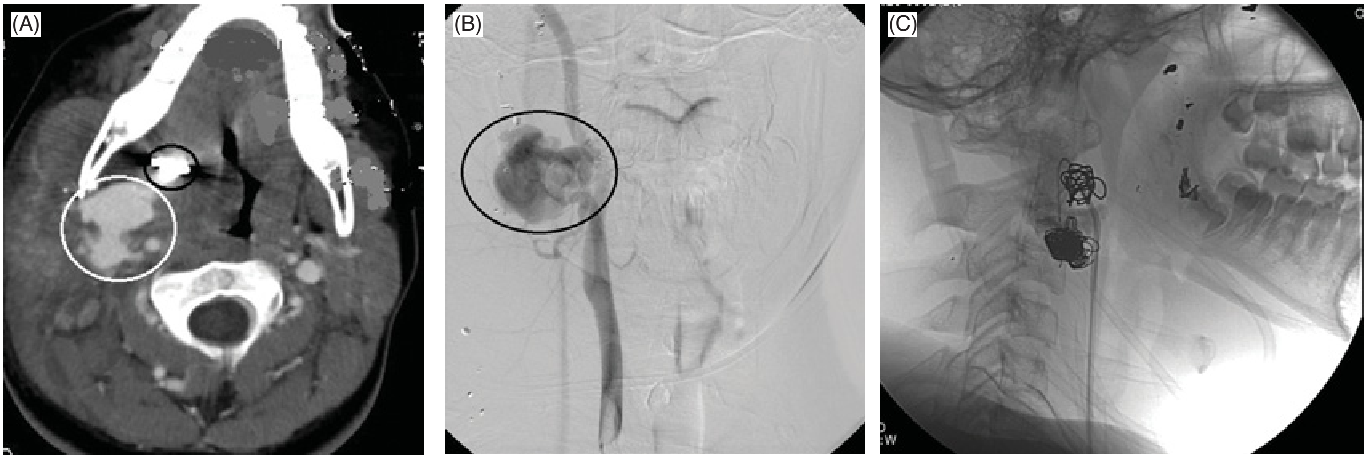


Figure 3.33 A–C Penetrating injury to zone III of the neck. CTA showing a large false aneurysm of the external carotid artery (A). Angiography confirms the presence of the aneurysm (B). The patient was successfully managed with coil embolization (C).

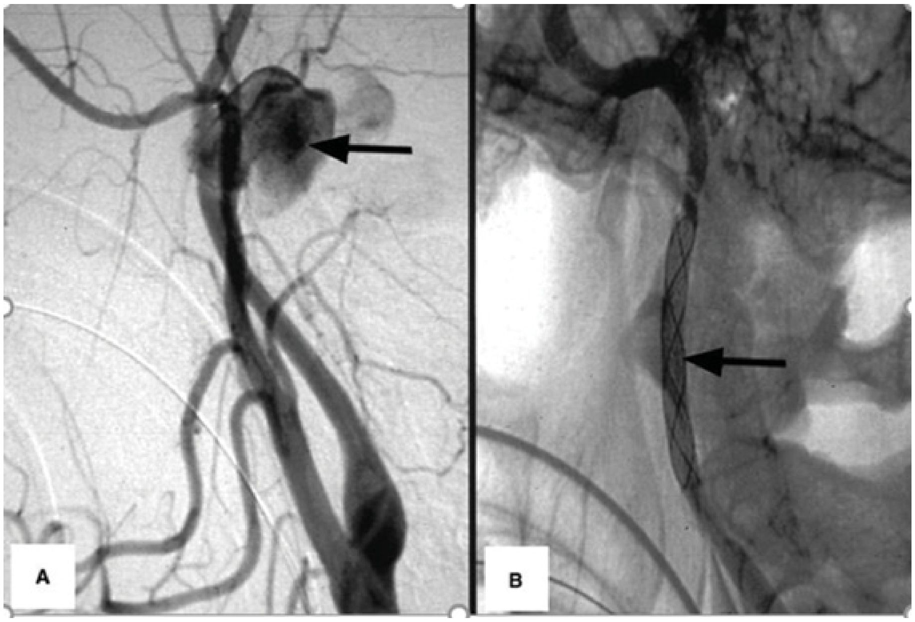


Figure 3.34 A,B Low-velocity gunshot wound to zone III of the neck. Angiography showing a large false aneurysm in the internal carotid artery (A). The aneurysm was successfully managed with endovascular stent-graft placement (B).

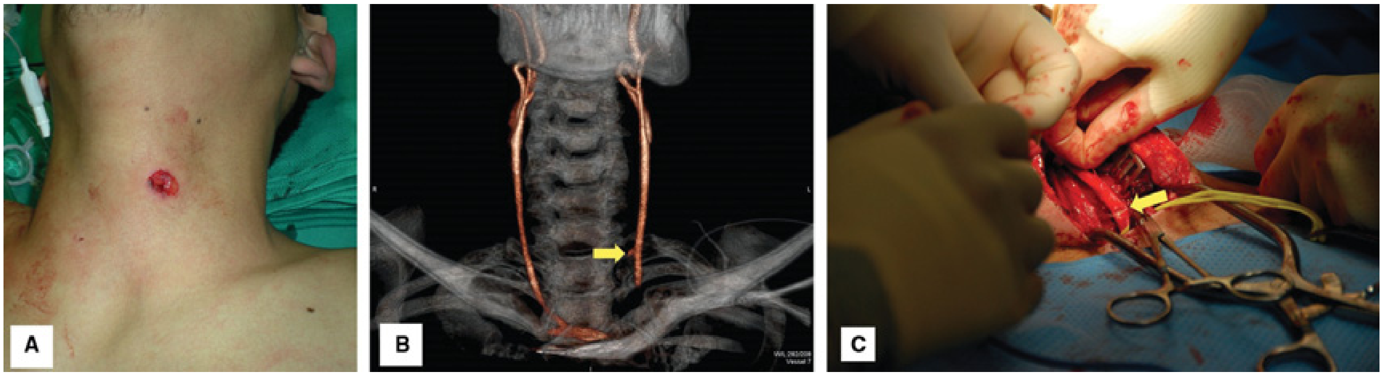


Figure 3.35 A–C Patient with a stab wound in zone II of the neck (A). CT angiogram, with 3-D reconstruction, shows a small common carotid false aneurysm (arrow; B). Intraoperative appearance of the carotid injury after opening the aneurysm (arrow; C).

Traumatic thrombosis of the common or internal carotid artery may result in ipsilateral anemic infarction and brain edema. In some cases, the occlusion may be well tolerated due to an intact circle of Willis. Early revascularization, ideally within the first four hours, is associated with good results. In patients with neurological deficits presenting early, emergency revascularization provides the best chances for neurological improvement. Delayed revascularization after six to eight hours, after the establishment of an anemic infarction, may worsen the brain edema or lead to a hemorrhagic infarction. Early surgical reconstruction remains the mainstay of management of penetrating carotid injuries (Figure 3.36 A–C).

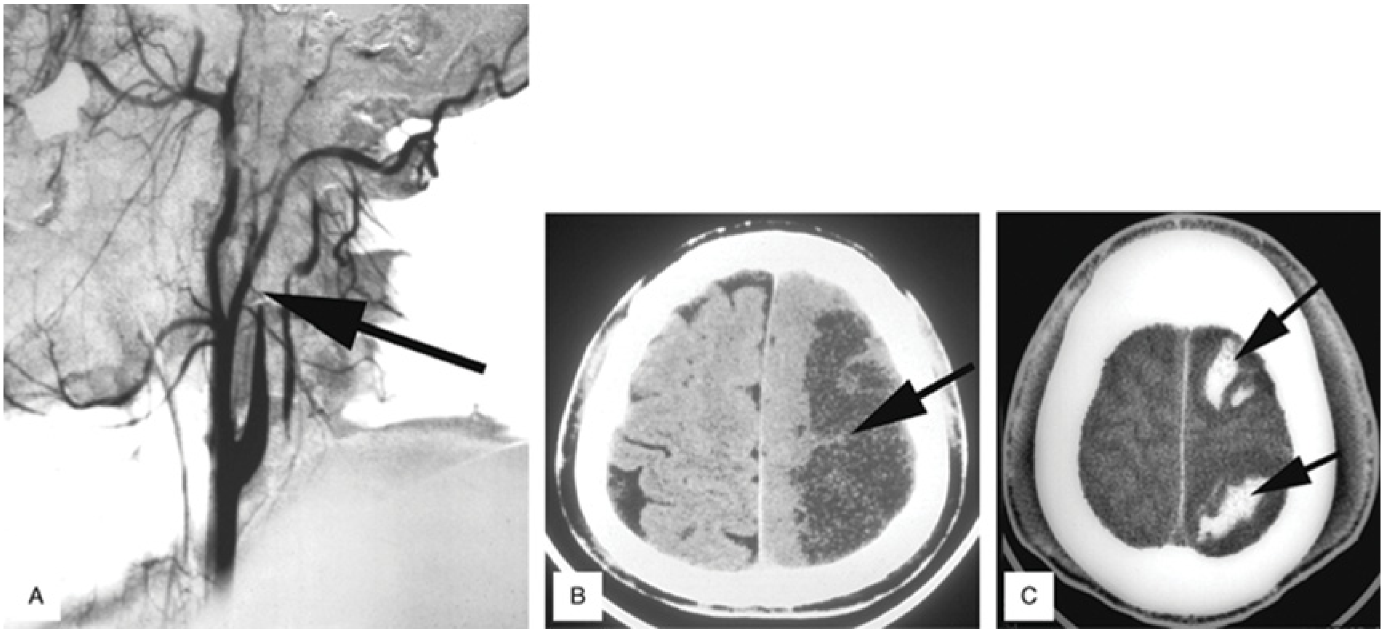


Figure 3.36 A–C Gunshot wound to the neck with carotid injury and neurological deficits on admission. Angiography showing injury with thrombosis of the internal carotid artery (arrow; A). CT scan of the brain showing an ischemic infarct (arrow; B). CT scan of the brain 1 day after revascularization showing conversion of the anemic infarction to a hemorrhagic one (arrows; C).

Penetrating Trauma to the Vertebral Artery

Vertebral artery trauma is diagnosed in about 3% of all penetrating injuries to the neck. Occlusion of a vertebral artery is usually tolerated well, and there is no need to attempt revascularization. In rare occasions with insufficient collateral circulation, occlusion of a vertebral artery may cause neurological deficits. The majority of vertebral artery injuries can be managed by observation or angiographic embolization. Surgical intervention is indicated only in the presence of severe active bleeding or in cases where angiographic embolization has failed (Figure 3.37, Figure 3.38 A,B).

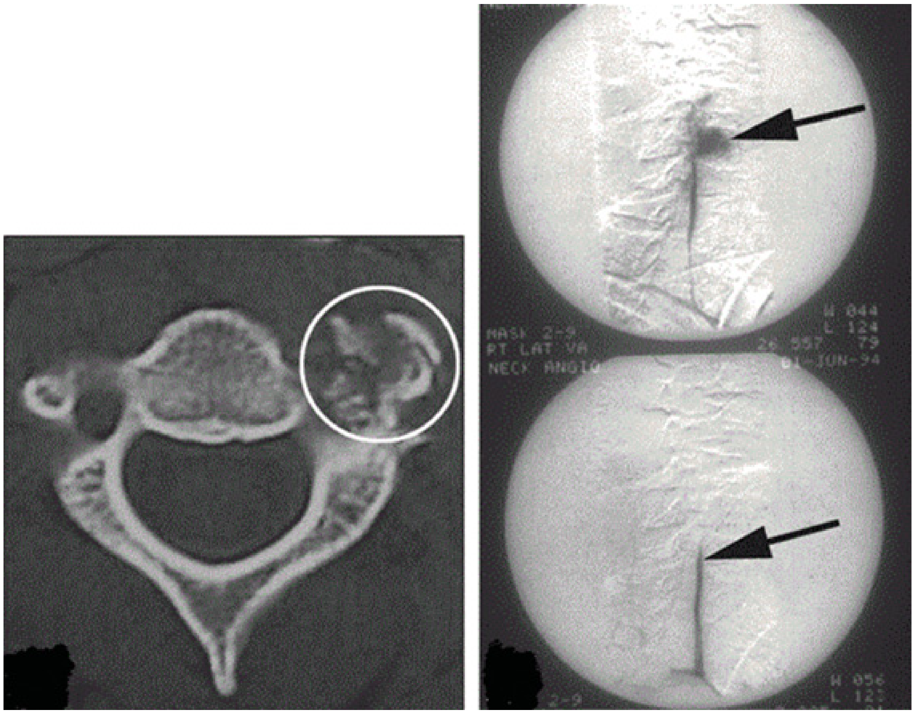


Figure 3.37 CT scan of a patient with a gunshot wound in zone III of the neck with a fracture of the vertebral foramen (circle; left). CTA showing a false aneurysm of the distal vertebral artery (arrow; upper right). This patient was treated successfully with angioembolization (arrow; lower right).

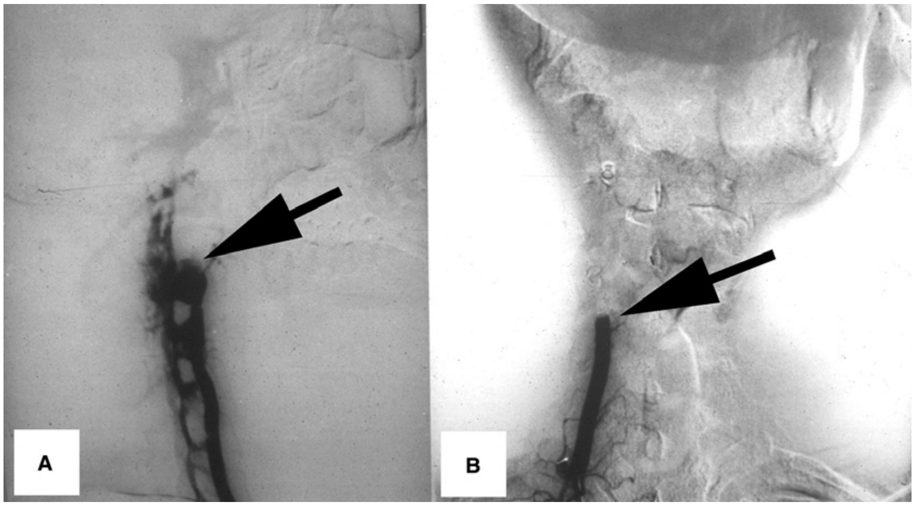


Figure 3.38 A,B Gunshot wound to the neck with a hematoma and bruit on auscultation. Angiogram shows an arteriovenous fistula between the vertebral artery and veins (A). Successful angioembolization was performed (B).

Penetrating Trauma to the Subclavian Vessels

Subclavian vascular injuries are diagnosed in about 3% of hospital admissions with penetrating neck trauma. More than 20% of these patients have no vital signs on admission and may benefit from an emergency room resuscitative thoracotomy. The deaths are typically the result of massive bleeding or air embolism in cases of venous injury. After thoracotomy, the bleeding can temporarily be controlled by digital compression or balloon tamponade, as described previously. In suspected venous injuries, the patient should be placed in the Trendelenburg position to prevent air embolism. Immediate operative intervention in cases with active bleeding remains the cornerstone of survival. Patients with no active bleeding (pseudoaneurysm, thrombosis, or arteriovenous fistula) should be considered for angiointervention and stent-graft placement (Figure 3.39, Figure 3.40).

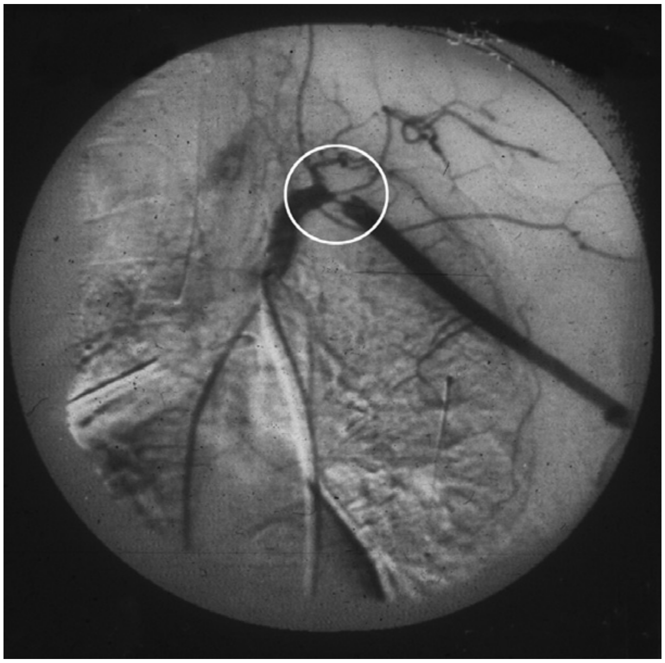


Figure 3.39 Patient with a stab wound to zone I of the neck, presenting with diminished radial pulse. The angiogram shows injury (circle) to the proximal subclavian artery. This patient can be managed operatively or with an endovascularly placed stent-graft.

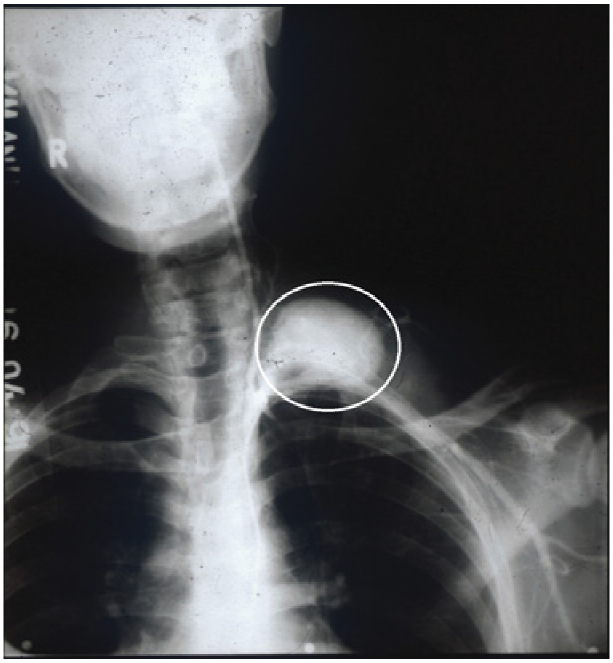


Figure 3.40 Patient with a stab wound to zone I of the neck, presenting with pulsating mass in the left supraclavicular area and diminished radial pulse. Angiography showing a large subclavian artery false aneurysm (circle). This patient can be managed operatively or by angiographically placed stent-graft.

Blunt Neck Trauma

Blunt trauma to the neck usually involves the musculoskeletal structures. However, in some cases, it may involve the vessels or the laryngotracheal tract.

Blunt Vascular Injuries

Cervical cerebrovascular injuries occur in less than 1% of all blunt trauma admissions and may involve the carotid or the vertebral arteries. The injury is often an intimal tear, but it can be thrombosis, complete avulsion, or a false aneurysm. The patient is often asymptomatic initially, and because of the often low index of suspicion, the diagnosis may be delayed or missed. Failure to treat these injuries early can result in delayed neurological deficits due to thrombosis. This complication may occur many days or even weeks after the initial injury. It is essential that patients at risk for this injury should be screened by CTA. Criteria for screening for cerebrovascular injuries include seat-belt sign or any bruising or hematoma to the neck after blunt trauma; unexplained neurological deficits; severe maxillofacial injuries; cervical spine fractures with subluxation, especially if there is involvement of the transverse foramen; hanging; or fractures of the base of the skull with carotid canal involvement.

The usual mechanism of vascular trauma is overextension of the neck, although overflexion of the head or direct trauma to the neck may result in such injuries as well. The most common site of blunt carotid trauma is the proximal internal carotid artery, near the bifurcation. Another site of injury is the internal carotid at the C2 level, due to stretching of the vessel over the transverse process of C2, after neck overextension. The clinical picture may vary from an asymptomatic seat-belt mark sign or neck hematoma to severe neurological deficits such as hemiparesis or hemiplegia or coma (Figure 3.41 A–D, Figure 3.42 A,B, Figure 3.43 A,B, Figure 3.44, Figure 3.45 A–C).

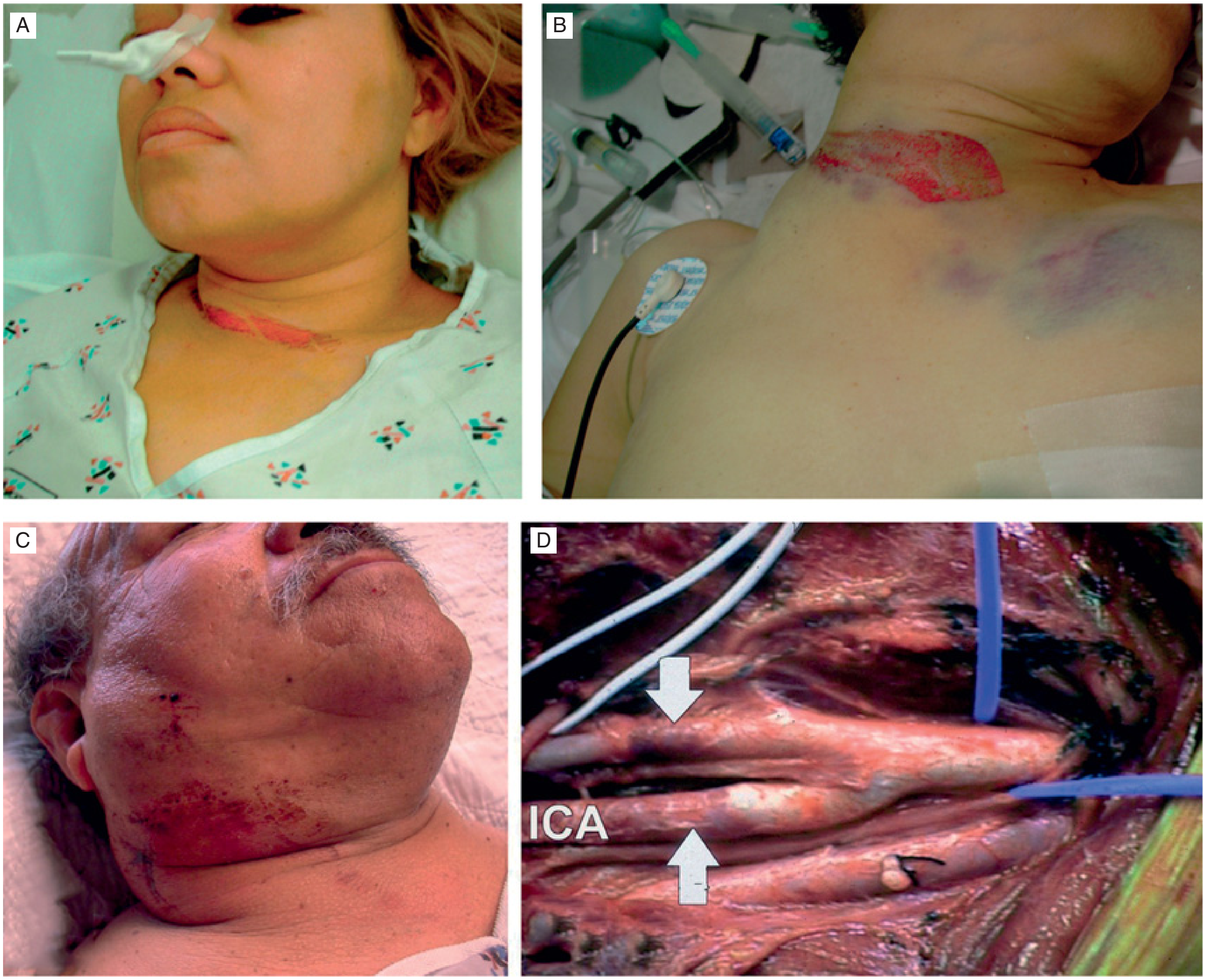


Figure 3.41 A–D Asymptomatic seat-belt mark in the neck. These patients should always be evaluated by CT angiogram to evaluate for occult injuries to the carotid or the vertebral arteries (A). Asymptomatic seat-belt mark in the neck and bruising in the left periclavicular area. This patient should always be evaluated by CT angiogram to evaluate for occult injuries to the neck vessels and the subclavian vessels (B). Patient with seat-belt sign on the right side of the neck and unexplained hemiplegia (C). The intraoperative findings show the carotid contusion and underlying thrombosis of the internal and external carotid arteries (arrows; D).

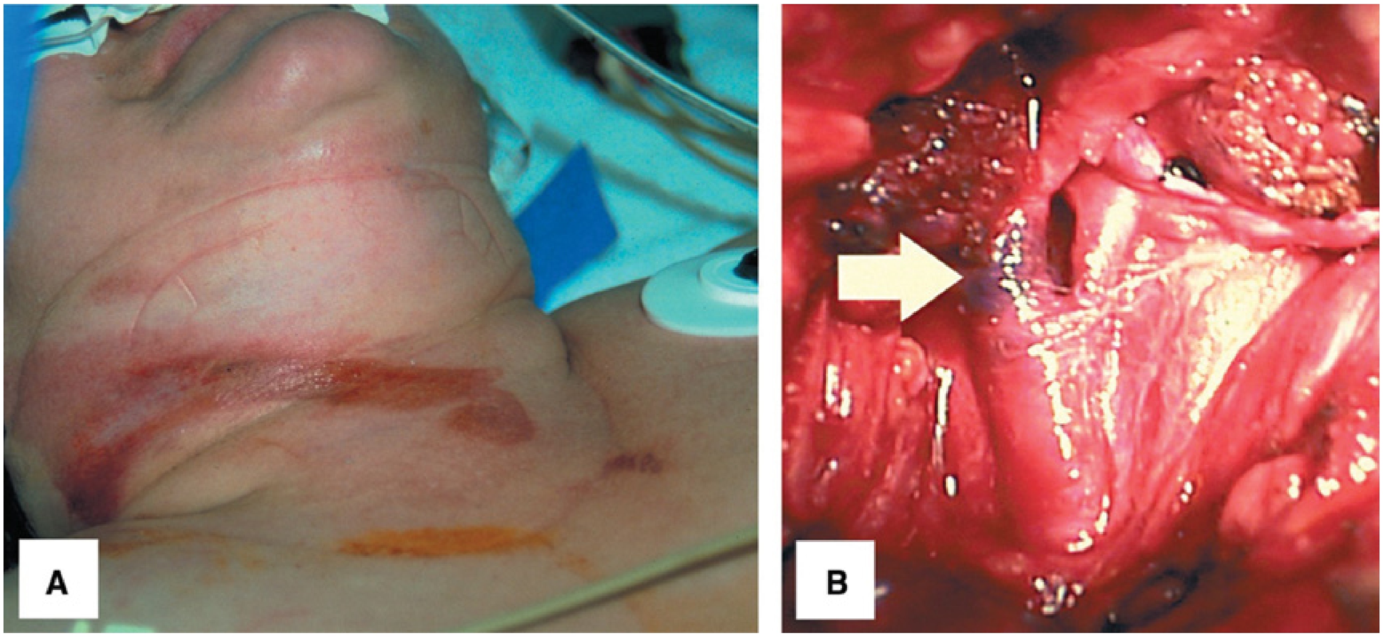


Figure 3.42 A,B Patient with seatbelt sign on the neck and left hemiparesis (A). Surgical exploration shows bruising and underlying thrombosis of the internal carotid artery (arrow; B).

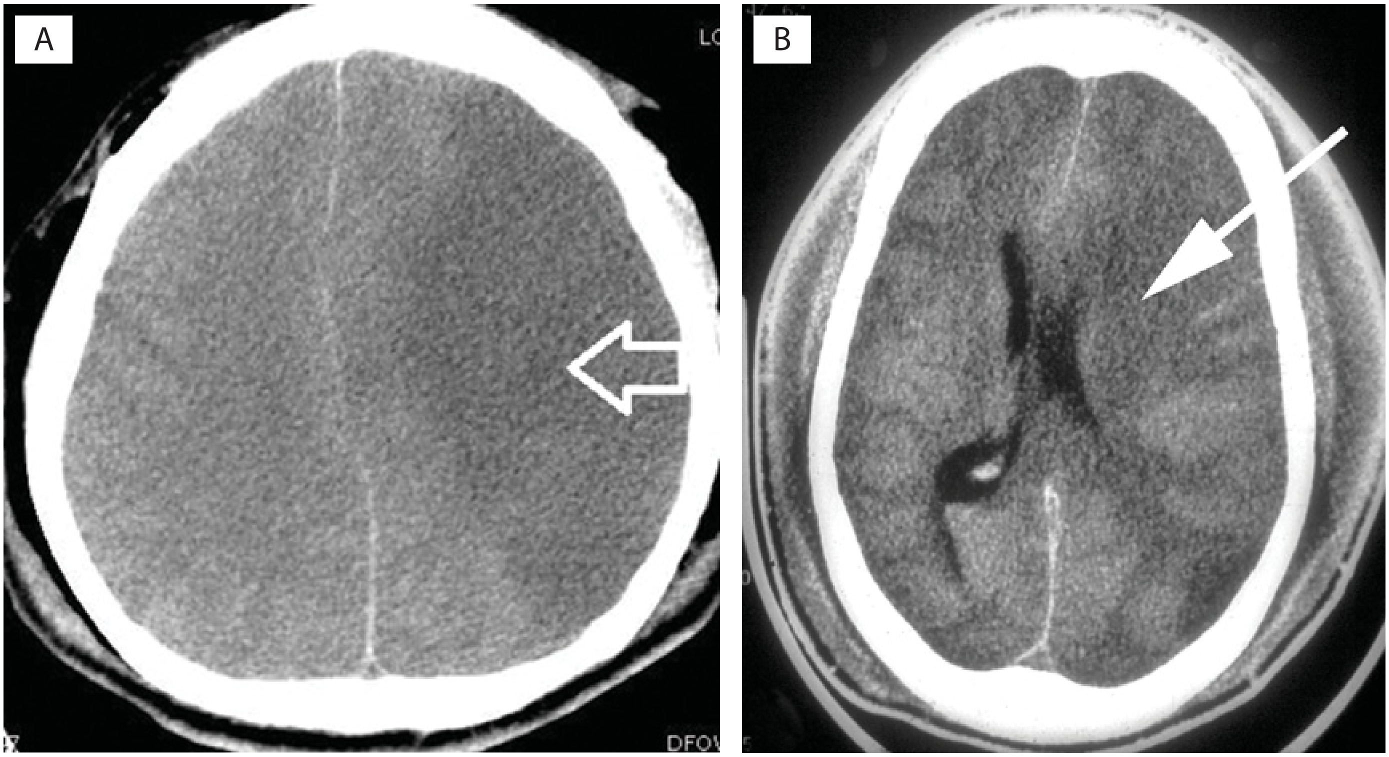


Figure 3.43 A,B Patient involved in a motor vehicle accident with a seat-belt mark on the neck and in coma. CT scan shows a massive left anemic brain infarction (arrow) due to thrombosis of the left internal carotid artery (A). Patient involved in a motor vehicle accident. On initial evaluation, besides a small seat-belt mark sign on the left side of the neck, he was asymptomatic and was discharged home. He returned four days later with right hemiplegia. CT scan shows anemic infarction (arrow), brain edema, and midline shift of the left hemisphere due to thrombosis of the left internal carotid artery (B).

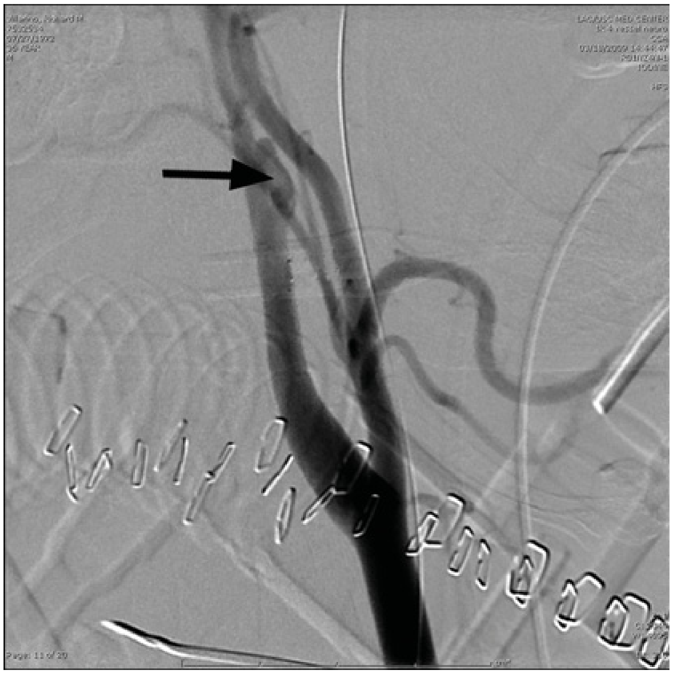


Figure 3.44 Angiography showing a pseudoaneurysm of the distal internal carotid artery (arrow), following a motor vehicle injury. This patient was managed with endovascularly placed stent-graft combined with antiplatelet therapy.

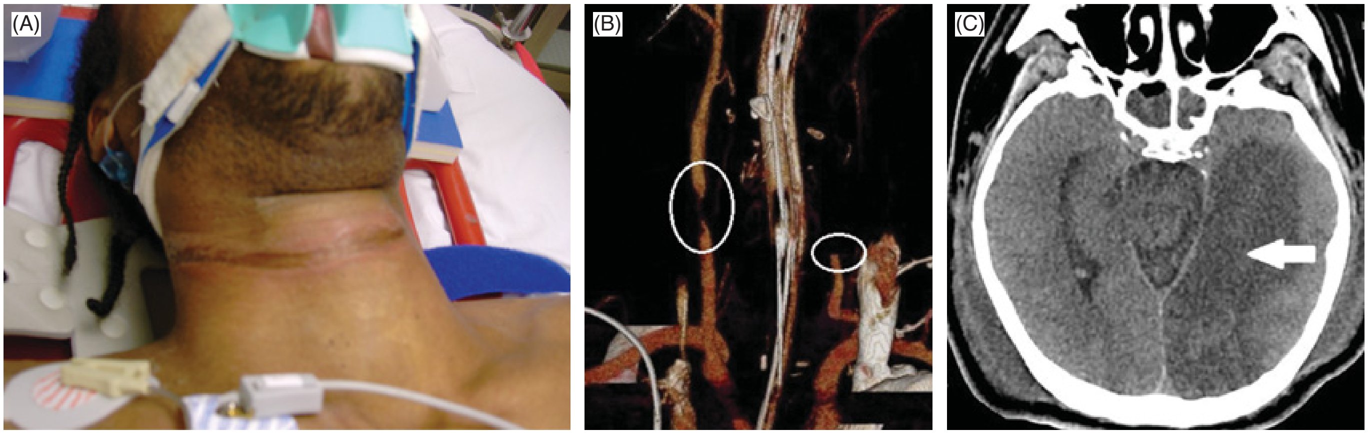


Figure 3.45 A–C Patient admitted in coma been found hanging (A). CT angiography showing occlusion of the right common carotid artery, with reconstitution and complete occlusion of the left common carotid artery without distal flow (arrows; B). CT of the brain showing a massive left cerebral anemic infarction (circle; C).

CTA, ideally with 3-D reconstruction, is the best screening tool. In addition, it provides information about any skeletal or laryngotracheal injuries. Formal angiogram is the diagnostic gold standard, but its routine use for screening purposes is limited because of its invasiveness. It has a significant role in the endovascular management of selected cases with dissection or pseudoaneurysm.

The treatment depends on the type and site of carotid injury and the experience of the surgeon. In severe injuries to the proximal carotid that are easily accessible surgically, an operation with reestablishment of the blood flow by means of a homologous venous graft is recommended.

Most cases with minor blunt carotid trauma, such as intimal tears, can be managed nonoperatively, with anticoagulants or antiplatelet medications (Figure 3.46). The treatment should be continued for three to six months, and the progression of the injury should be monitored with color flow doppler or CTA until resolution or stabilization. Early anticoagulation is essential in reducing the risk of progression of the thrombus and stroke. Angiographically placed stents should be considered in selected cases with severe common or internal carotid trauma, such as false aneurysm or thrombosis. The recommended management of blunt vertebral artery trauma is antiplatelet therapy for a few months.

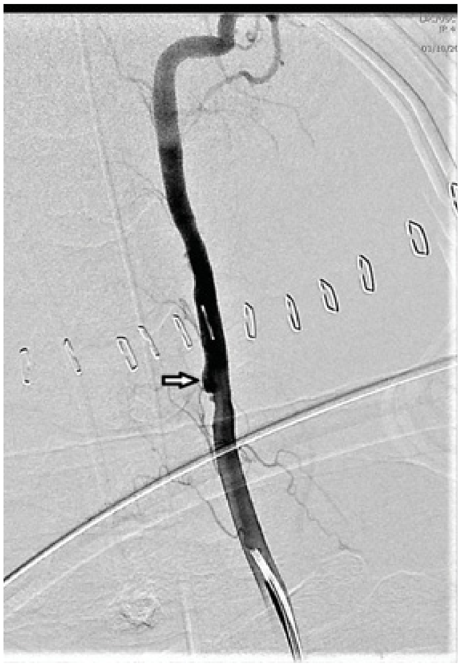


Figure 3.46 Patient with hyperextension injury to the spine. Angiogram shows a pseudoaneurysm in the right vertebral artery (arrow). These injuries should be managed with anticoagulation and antiplatelet therapy and follow-up CT angiogram.

Blunt Laryngotracheal Trauma

Blunt trauma to the larynx or trachea may occur as a result of direct trauma to the neck, hanging injuries, or anteroposterior crush trauma to the chest, which causes intratracheal high pressures while the glottis is closed. Also, deceleration injuries may cause shearing injuries at fixed points, such as the cricoid or the carina. These injuries may vary from submucosal hematomas to complete transection. The patient often complains of pain in the neck, dyspnea, hemoptysis, or hoarseness. Physical examination and plain X-rays typically reveal subcutaneous emphysema. The diagnosis is confirmed by CT scan of the larynx or endoscopy (Figure 3.47, Figure 3.48).

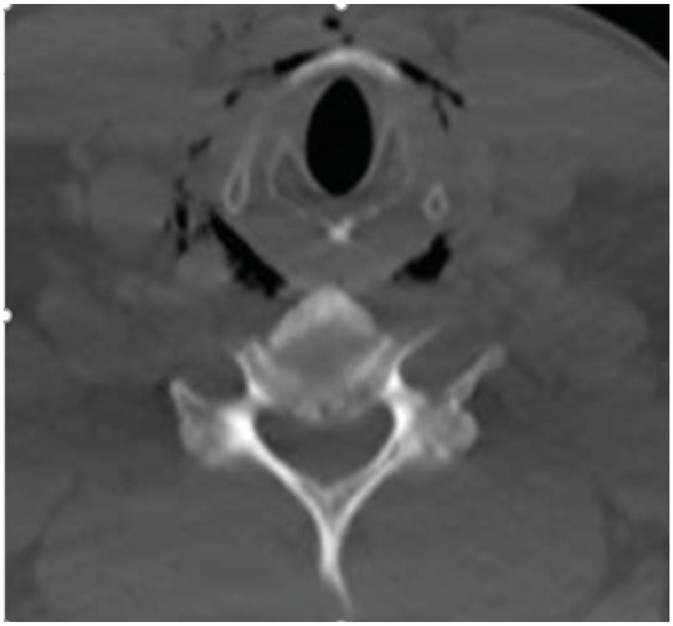


Figure 3.47 Blunt trauma to the anterior neck. Patient presents with hoarseness and subcutaneous emphysema. CT scan demonstrates rupture of the larynx with extensive soft tissue gas (arrows).

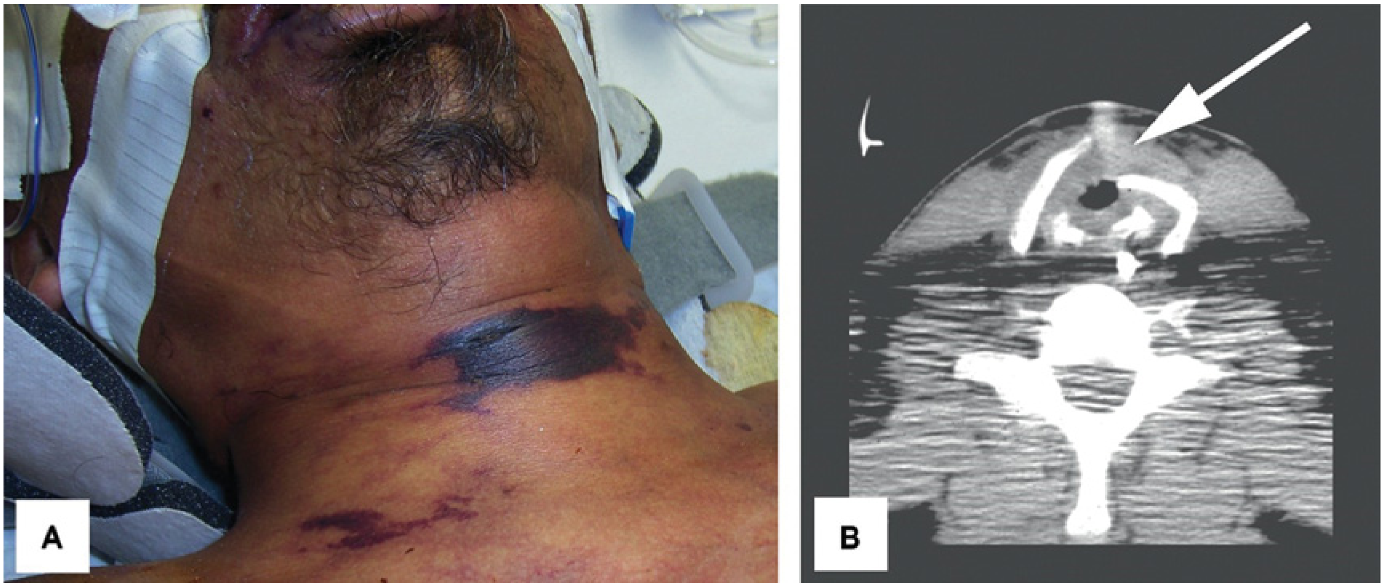


Figure 3.48 A,B Patient with blunt force trauma to the anterior neck (A). CT scan showing fracture of the larynx (arrow; B).

About 25% of patients with blunt laryngotracheal trauma require emergency airway control. Depending on the severity of the injury and the condition of the patient, the airway can be established by orotracheal intubation, fiberoptic intubation, or surgical airway. Many patients with no airway problem and with no major disruption of the laryngotracheal structures may be managed nonoperatively. Perforation of the larynx or trachea or major fractures of the thyroid or arytenoid cartilages or the hyoid bone often need surgical intervention.

Chapter

4

Thoracic Injury

Demetrios Demetriades and Peep Talving

Introduction

Chest trauma is estimated to be the primary cause of death in 25% of traumatic mortalities and a contributing factor in another 25% of deaths. Good understanding of the pathophysiology of chest trauma and timely selection of the appropriate investigations and treatment are all critical components for optimal outcome.

Clinical Examination

ATLS principles should always be followed in the initial evaluation and management of the chest trauma patient.

During the primary survey, there are six life-threatening conditions that need to be identified and treated:

1. Airway obstruction
2. Tension pneumothorax
3. Open pneumothorax with a “sucking chest wound”
4. Flail chest
5. Massive hemothorax
6. Cardiac tamponade

During the secondary survey, there are an additional six potentially lethal chest injuries that should be identified and treated. The diagnosis of these conditions may need more complex and time-consuming investigations.

1. Lung contusion
2. Myocardial contusion (blunt cardiac trauma)
3. Aortic rupture
4. Diaphragmatic rupture
5. Tracheobronchial rupture
6. Esophageal injury

Investigations

History and clinical examination will determine the type and timing of investigations necessary for the safe and efficient evaluation of the chest trauma patient. In the unstable patient, therapeutic interventions such as thoracostomy tube insertion or thoracotomy may need to be initiated prior to any investigation due to imminent arrest. In all other patients, when the diagnosis is uncertain, the following investigations may be useful in chest trauma:

1. Focused assessment with sonography for trauma (FAST): FAST is an important investigation and should be immediately available in the emergency department. Emergency physicians and trauma surgeons should be trained in its use, as it allows early diagnosis of cardiac tamponade or hemoperitoneum at the bedside with high accuracy (see Chapter 25, Ultrasound in Trauma). The extended FAST (EFAST) provides additional information regarding hemo- and pneumothoraces.
2. Chest X-ray: Ideally chest X-ray should be taken during deep expiration and in the upright position, for the most accurate detection of small pneumothoraces, hemothoraces, and mediastinal abnormalities. In many cases, this is not possible because of associated hemodynamic instability, depressed level of consciousness, or concern about spinal injury. In evaluation of the chest X-ray, a systematic approach should be adopted that allows evaluation for pneumothorax, hemothorax, lung contusion, subcutaneous or mediastinal emphysema, fractures, mediastinal widening, enlarged cardiac shadow, pneumopericardium, elevated diaphragm or suspicious shadows suggestive of diaphragmatic hernia, free air under the diaphragm, and foreign bodies.
3. Electrocardiogram (EKG): EKG should be performed in all patients with severe blunt chest trauma and suspected cardiac trauma. In addition, EKG might be useful in some stable patients with suspected penetrating cardiac injuries.
4. Pericardiocentesis: This diagnostic procedure has little or no value in the evaluation of suspected cardiac trauma in a modern trauma center, as it is associated with an unacceptably high incidence of false-negative results because of clot formation in the pericardium. In addition, it is a potentially dangerous procedure because of the risk of myocardial or coronary vessel perforation, especially if performed in the absence of hemopericardium. It might have a role for temporary decompression of a tense hemopericardium in selected cases where a surgeon is not immediately available.
5. Subxiphoid pericardial window: This major invasive procedure has been used by some surgeons to diagnose cardiac tamponade. However, with the availability of EFAST, the subxiphoid window is rarely or almost never indicated. Intraoperative transdiaphragmatic window during an exploratory laparotomy, however, remains a useful diagnostic tool for the evaluation of cardiac involvement after penetrating thoracoabdominal injuries.

6. CT and CTA: CT imaging is the most valuable investigation in blunt trauma for the evaluation of the mediastinum, aorta, thoracic spine, and suspected lung contusions. All stable blunt trauma patients with a suspicious mechanism of injury (high-speed injury, falls from height) or those with an abnormal mediastinum on chest X-ray should be evaluated by CTA for aortic rupture. CTA is highly sensitive and specific in detecting aortic rupture and has replaced aortography as the standard of care. CTA also has a definitive role in the evaluation of selected patients with penetrating chest trauma. In patients with transmediastinal gunshot wounds who are hemodynamically stable, a high-quality CTA may be useful in identifying the bullet track and in determining the need for further investigations, such as endoscopy or esophageal contrast swallow studies. If the direction of the bullet track is away from the major vessels, esophagus, and other important mediastinal structures, no further investigations are necessary. CT scan is also useful in the evaluation of persistent opacifications on chest X-ray, following the insertion of a thoracostomy tube. In these cases, a CT scan without contrast may be utilized to help distinguish between the potential differential diagnoses of atelectasis, contusion, and residual hemothorax.
7. Catheter angiography: Diagnostic angiography has largely been replaced by CTA, although it still has an important role in the evaluation of patients with shotgun injuries with multiple pellets. Therapeutic catheter angiography and placement of stent-grafts, however, play a major role in the management of traumatic thoracic aortic injuries, false aneurysms, and arteriovenous fistulas of the major thoracic inlet arteries.
8. Color flow doppler: Color flow doppler ultrasound is a good noninvasive vascular study that can reliably evaluate the subclavian and neck vessels, and it can be used in hemodynamically stable patients with thoracic inlet penetrating injuries. Its major weaknesses include operator-dependent accuracy, immediate availability, and inability to visualize the left proximal subclavian vessels, especially in obese patients.
9. Endoscopy: Esophagoscopy and bronchoscopy may be necessary for suspected aerodigestive tract injuries, usually as a result of mediastinal penetrating trauma or mediastinal emphysema on plain X-ray or CT.
10. Diagnostic laparoscopy: Diagnostic laparoscopy has a definitive role in the evaluation of the diaphragm in asymptomatic patients with left thoracoabdominal or selected right thoracoabdominal penetrating injuries. Patients that have been ruled out for hollow viscus or abdominal injury requiring an operation are evaluated by diagnostic laparoscopy with laparoscopic diaphragmatic repair if an injury is identified. Failure to recognize and repair a diaphragmatic injury may result in a diaphragmatic hernia with visceral strangulation at a later stage. Right posterior thoracoabdominal injuries do not need evaluation and repair of the diaphragm because the presence of the liver protects against herniation of intra-abdominal organs.
11. Thoracoscopy: Thoracoscopy is used in the evaluation of diaphragmatic injuries, especially in the posterior region and for the evacuation of residual hemothorax. It has the disadvantage of requiring double-lumen intubation and lung collapse, which may be technically demanding and sometimes not well tolerated by the patient, especially if there is a contralateral lung injury.
12. Troponin levels: Serial troponin measurements should be considered in suspected blunt cardiac trauma. Troponin levels do not correlate with the severity of the myocardial trauma. In addition, many patients with severe extrathoracic injuries, such as head trauma or acute kidney injury, may have elevated troponin levels.
13. Arterial blood gas (ABG): ABG monitoring should be considered in all severe chest trauma cases in order to assess severity, plan treatment, and monitor progress of treatment.

General Management

In an urban environment, there is no place for prehospital attempts to stabilize patients with severe chest trauma, and the principle of “scoop and run” should be applied. The patient should be placed on a spinal board, receive oxygen by mask, and be transferred without any delay to the nearest trauma hospital. Intravenous access should be attempted in the ambulance en route. In patients with severe respiratory distress and clinical suspicion of tension pneumothorax, a needle thoracostomy at the 4th or 5th intercostal space at the anterior axillary line may be attempted. Open sucking wounds should be covered with commercially available chest seals or a clean square gauze, taped only on three sides to avoid a tension pneumothorax. Patients with respiratory failure will need prehospital intubation or bag-valve mask ventilation en route. In the emergency department, the primary survey will determine the need and type of immediate treatment. Patients with imminent or established cardiac arrest should be managed with an emergency department resuscitative thoracotomy. Any bleeding is controlled by sutures, clamping, or manual compression. Aortic cross-clamping is performed, and cardiac massage is initiated. Transfusion with O-negative (women of child-bearing age) or O-positive blood, ACLS medications, calcium, sodium bicarbonate, and defibrillation are administered as warranted. If cardiac activity returns, the patient is transferred to the operating room for completion of the operation.

Patients with severe hypotension and suspicion of cardiovascular trauma should be taken directly to the operating room with minimal investigations. All investigations are targeted at determining the location of operative incision. A FAST is very valuable in that it can rapidly evaluate the pericardial, bilateral thoracic, and peritoneal spaces.

Hemodynamically stable patients are examined carefully, and further investigations are performed as indicated.

Thoracostomy tubes, analgesia, intubation, and mechanical ventilation may be necessary.

Elderly patients with multiple rib fractures or significant lung contusions, despite a normal respiratory status on initial examination, should be admitted to the ICU for close monitoring. Early, liberal endotracheal intubation and mechanical ventilation should be considered because elderly patients have limited physiologic reserves and often deteriorate rapidly and with little warning. Adequate analgesia by means of epidural or patient-controlled analgesia (PCA) is a critical component of the management of these cases, as these patients often deteriorate several hours after admission, despite apparent stability on admission.

Indications for Thoracotomy

Fewer than 5% of blunt chest trauma, approximately 15% of stab wounds, and approximately 20% of gunshot wounds require thoracotomy. The majority of patients with chest trauma can be safely managed with a thoracostomy tube and other supportive treatment. The indications for urgent thoracotomy include the following:

- Cardiac arrest or imminent cardiac arrest
- Evidence of significant thoracic injury with hypotension or active bleeding
- Immediate blood loss in the thoracostomy tube of more than 1,000–1,200 ml
- Diagnosis of esophageal or tracheobronchial injury

Semielective thoracotomy is indicated for large residual hemothoraces or persistent large air leaks when proximal airway injury is suspected.

Tips and Pitfalls

1. Elderly patients with multiple rib fractures or lung contusions may seem stable on admission, but rapid respiratory deterioration may occur a few hours later. Consider admission to the ICU for close monitoring in the event that early endotracheal intubation or mechanical ventilation is needed.
2. Patients with flail chest may seem stable on admission. Decompensation with severe respiratory failure may occur with potentially catastrophic consequences. Liberal early intubation is recommended, particularly before these patients are transferred to the radiology suite for prolonged investigations.
3. A widened mediastinum following a motor vehicle or motorcycle collision or a fall from height may be due to rupture of the thoracic aorta or to fractures of the thoracic spine or the sternum or cardiac tamponade.
4. Traumatic rupture of the thoracic aorta may not be associated with an abnormal mediastinum on chest X-ray. In high-speed deceleration trauma, all patients should be evaluated by chest CT scan to rule out aortic injuries.
5. In asymptomatic left thoracoabdominal penetrating injuries, routine laparoscopy should be performed on all asymptomatic patients. Diaphragmatic injuries are common, and CT imaging is often not a reliable diagnostic tool.

Chest Wall and Soft Tissues

Seat-belt marks on the thoracic wall are indicators of severe trauma, and 20% of these patients have significant intrathoracic injuries. These patients should have routine evaluation for lung contusion, myocardial contusion, aortic rupture, and hemopneumothorax (Figure 4.1 A–C).

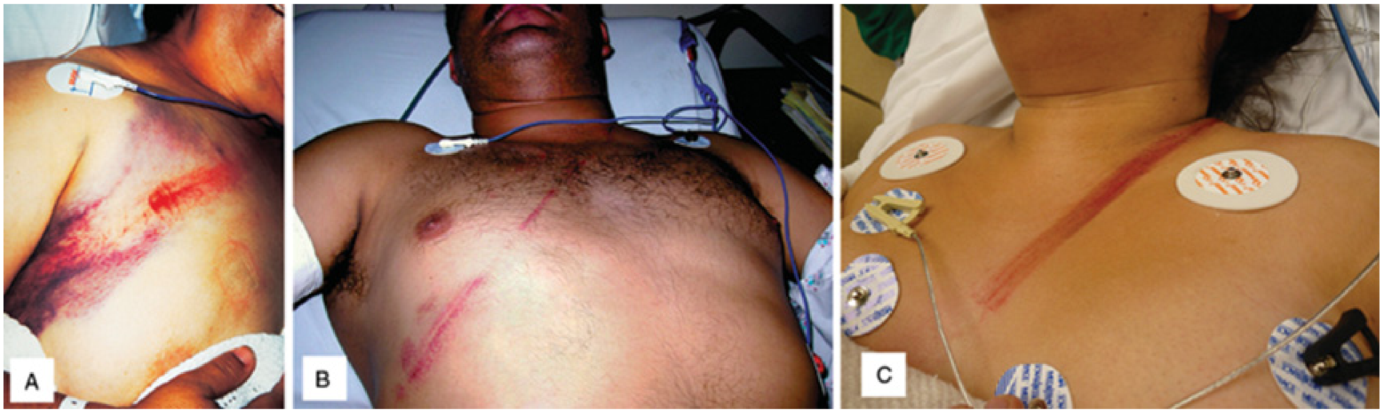


Figure 4.1 A–C Chest seat-belt marks are markers of significant internal injuries and should be evaluated by CT scan, EKG, and troponin levels.

Rib Fractures

Fracture of the Upper (First or Second) Ribs

Fractures of the upper ribs, especially the first rib, are associated with a high incidence of subclavian and other major vascular injuries. The force required to fracture an upper rib is severe, and thus mediastinal structures, including the aorta, are at high risk with this mechanism. A CTA of the chest is indicated to evaluate for aortic and great vessel injuries. Children have a much more compliant chest wall, and thus any rib fractures are significant, although CTA of the chest in the pediatric population is not routinely indicated, given the rarity of aortic and great vessel injury after blunt trauma (see Chapter 13, Pediatric Trauma) (Figure 4.2 A,B).

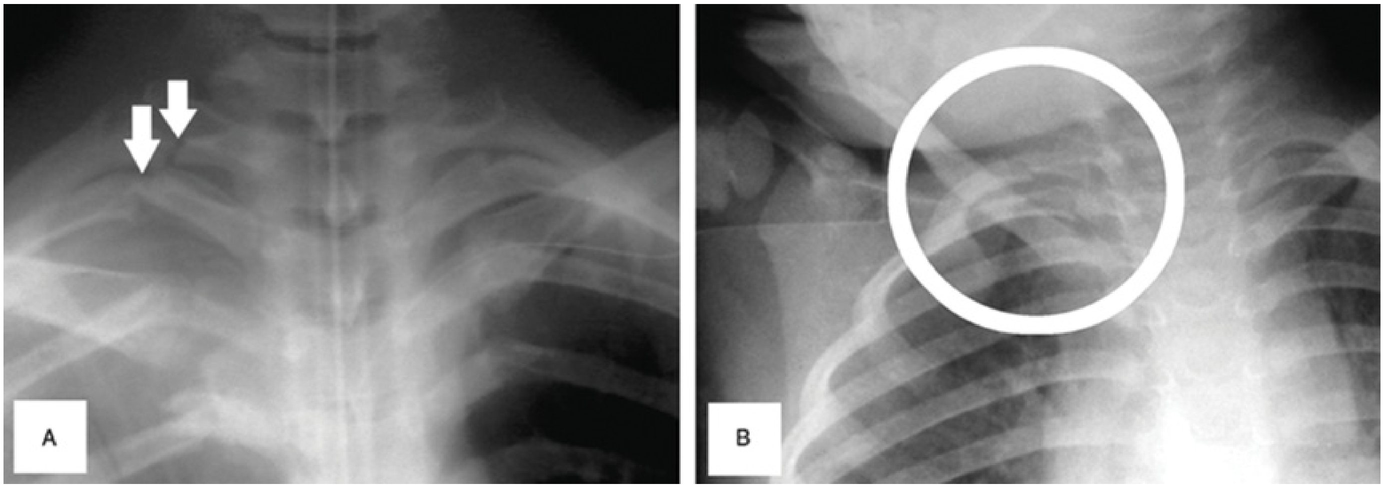


Figure 4.2 A,B Chest X-ray with fractures of the upper ribs. These cases should always be evaluated for thoracic inlet vascular injuries, especially the subclavian vessels.

Fracture of Middle (Third to Eighth) Ribs

Rib fractures are diagnosed clinically (pain aggravated by breathing or coughing, or pain on anteroposterior chest compression) or radiologically. Fractures at the costochondral junction may not show on X-rays. Associated injuries include hemopneumothorax, lung contusion, cardiac trauma, and diaphragmatic tear. Pain relief is extremely important, especially in elderly patients with multiple rib fractures, in order to prevent atelectasis and pneumonia. PCA or epidural or paraspinal analgesia should be considered in multiple fractures. Selected patients with significant functional or mechanical loss after severe rib fractures may be candidates for rib fixation procedures and should be evaluated by a surgeon capable of this procedure.

Rib fractures in children are uncommon and signify severe impact to the chest wall, and there is a high incidence of underlying lung contusion (Figure 4.3 A–C).

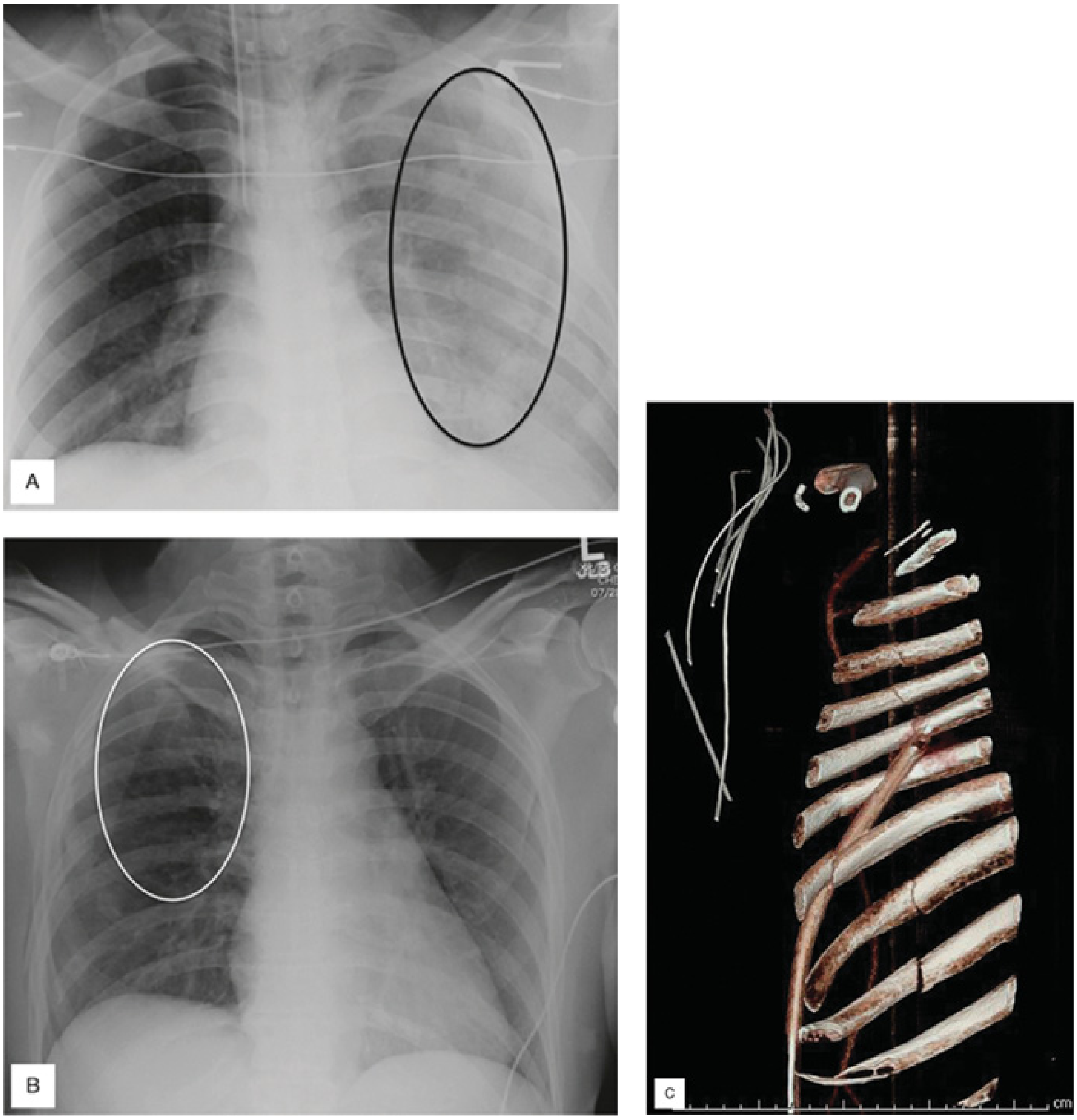


Figure 4.3 A–C Plain radiographs of multiple mid rib fractures, with underlying lung contusion (A). Multiple rib fractures on the right side with associated clavicular fracture. Adequate analgesia with epidural or patient-controlled analgesia should be considered early, especially in elderly patients (B). 3-D reconstruction of multiple mid rib fractures and a thoracostomy tube in place (C).

Fracture of the Lower (Ninth to Twelfth) Ribs

Fractures of the lower ribs are often associated with injuries to the kidneys, liver, diaphragm, or spleen. Liberal use of abdominal CT scan should be considered. Intervention is rarely required unless a fractured segment remains impaled in the solid organ (Figure 4.4 A,B).

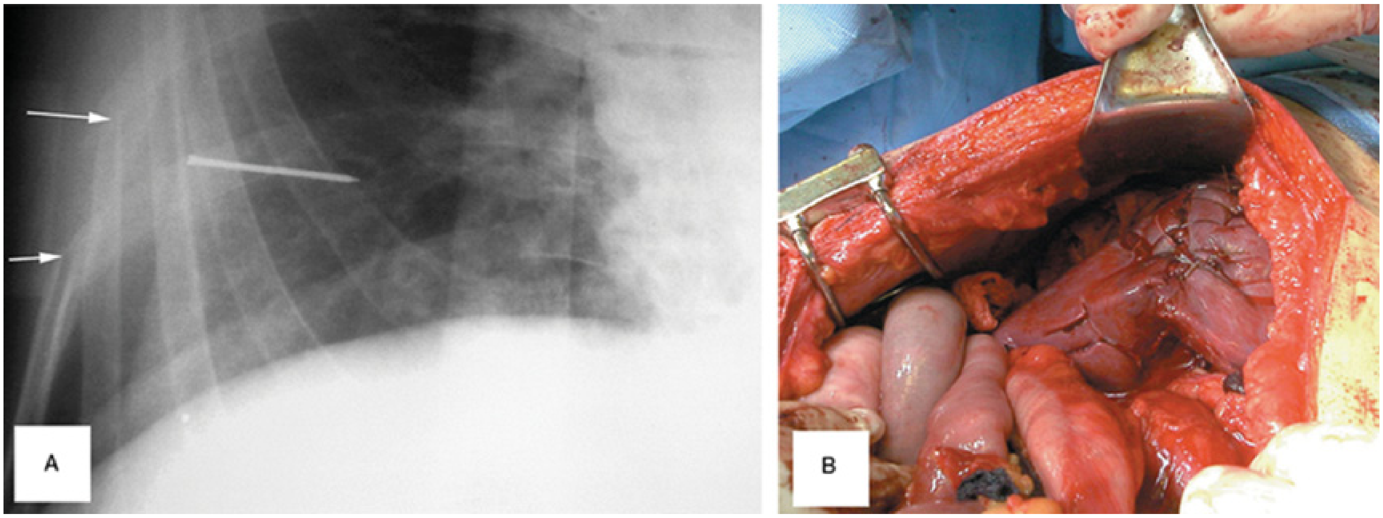


Figure 4.4 A,B Radiograph showing fractures of the right lower ribs (arrows;). Injuries to intra-abdominal solid organs are common and CT scan evaluation should be considered (A). Intraoperative photograph of the associated liver injury in the same patient (B).

Flail Chest

Flail chest is the result of anterior or lateral double fractures of at least three adjacent middle ribs. In most cases, there is an underlying lung contusion. Clinically, the flail segment moves paradoxically to normal chest wall motion, and the patient may be in respiratory distress. A thoracostomy tube should be considered, as it is indicated in most patients with flail chest and all patients should be monitored in an ICU setting with continuous pulse oximetry. Analgesia by means of PCA or epidural/paraspinal anesthesia should always be considered. Mechanical ventilation is often necessary for respiratory failure or imminent failure. Internal, operative fracture fixation may be useful in selected cases (Figure 4.5 A-E).

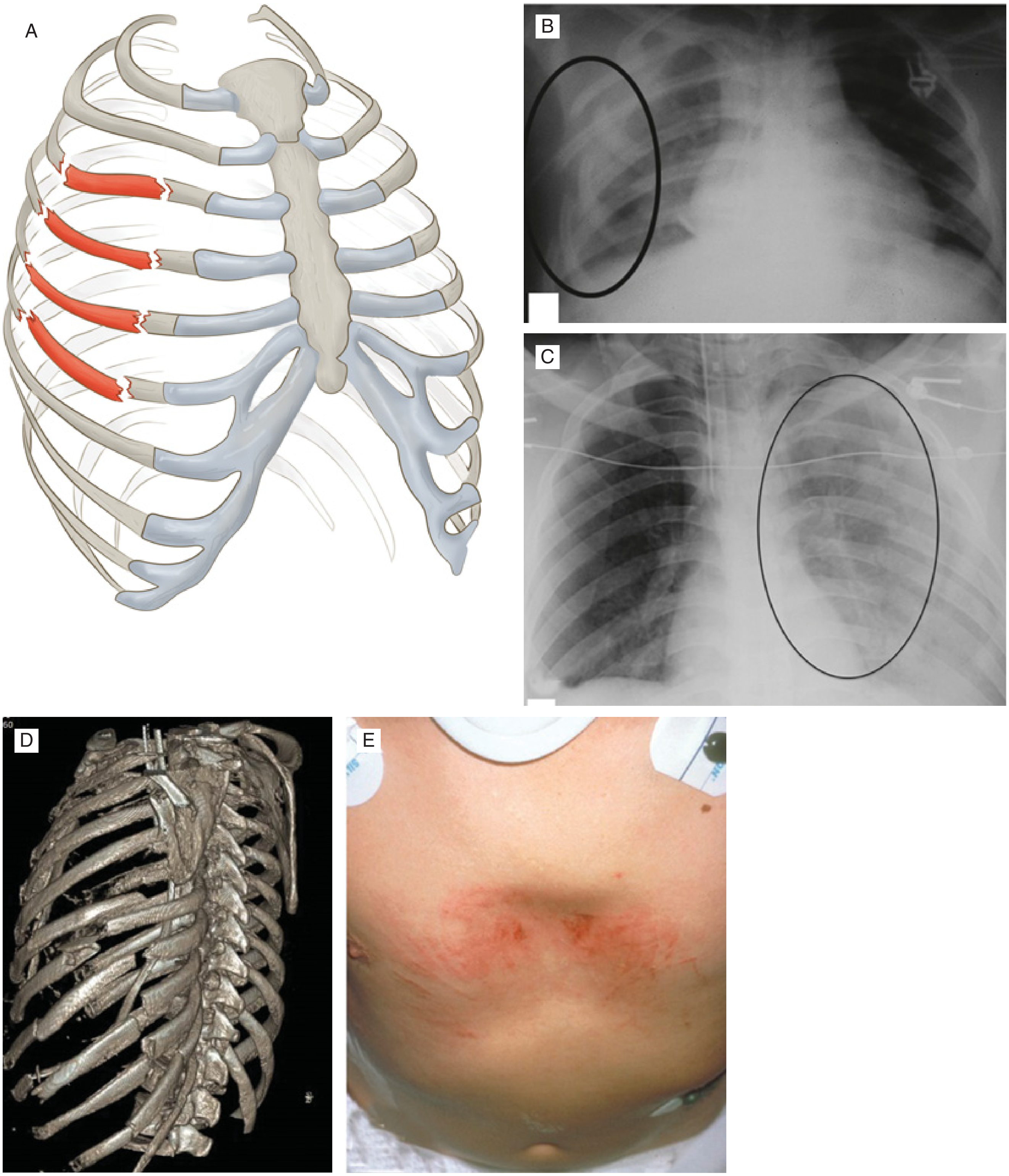


Figure 4.5 A–E Double fractures of at least three adjacent ribs are required in order to produce a flail chest (A). Chest X-rays showing multiple rib fractures, underlying lung contusion, and clinical flail chest. The diagnosis of flail chest is clinical (B, C). CT scan with 3-D reconstruction of multiple double rib fractures and clinical flail chest (D). Patient with a flail sternal segment; note the midsternal depression (E).

Hemo-Pneumothorax

Pneumothorax

A pneumothorax may be due to blunt or penetrating trauma. Small pneumothoraces are usually asymptomatic and can safely be managed without a thoracostomy tube, provided the patient does not need mechanical ventilation, prolonged, or air transportation. In these cases, any size pneumothorax should be treated with a thoracostomy tube to avoid the creation of tension pneumothorax. Large pneumothoraces may cause respiratory distress, and a tension pneumothorax can cause cardiorespiratory failure. The diagnosis of simple pneumothorax is usually made by chest X-ray or CT. An upright chest X-ray in deep expiration is the most suitable film to identify small pneumothoraces (Figure 4.6 A,B).

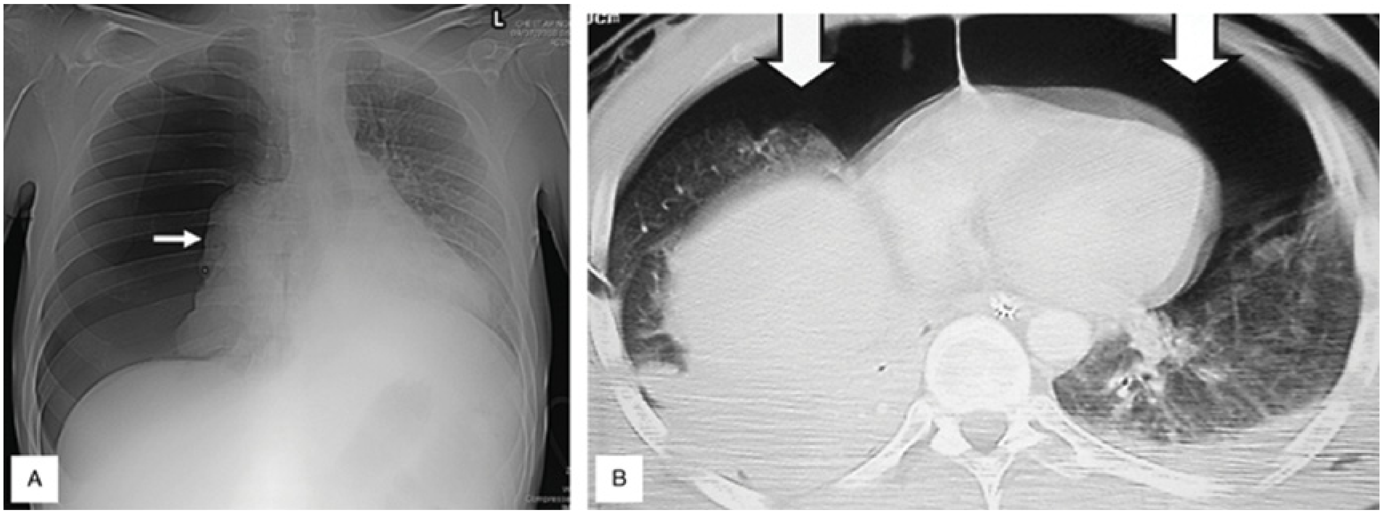


Figure 4.6 A,B Pneumothorax. Large right pneumothorax on chest X-ray. Arrow points to collapsed lung (A). Bilateral pneumothoraces on CT scan (arrows; B).

Tension Pneumothorax

In tension pneumothorax, air leaks into the pleural cavity with no escape route, due to a one-way valve effect. It is a life-threatening condition because of severe cardiorespiratory failure. The patient may appear panicky and have dyspnea, cyanosis, tachycardia, hypotension, and distended neck veins. The trachea may be shifted to the opposite side, there are no breath sounds, and there is hyperresonance on percussion in the affected hemithorax. Immediate life-saving intervention is needle decompression of the chest, followed by formal thoracostomy tube insertion. The mere suspicion of a tension pneumothorax is an absolute indication for a needle decompression whenever a thoracostomy tube cannot be inserted immediately (prehospital, austere environments, areas outside the emergency department or operative room). A thoracostomy tube should be subsequently inserted as soon as possible (Figure 4.7 A–G).

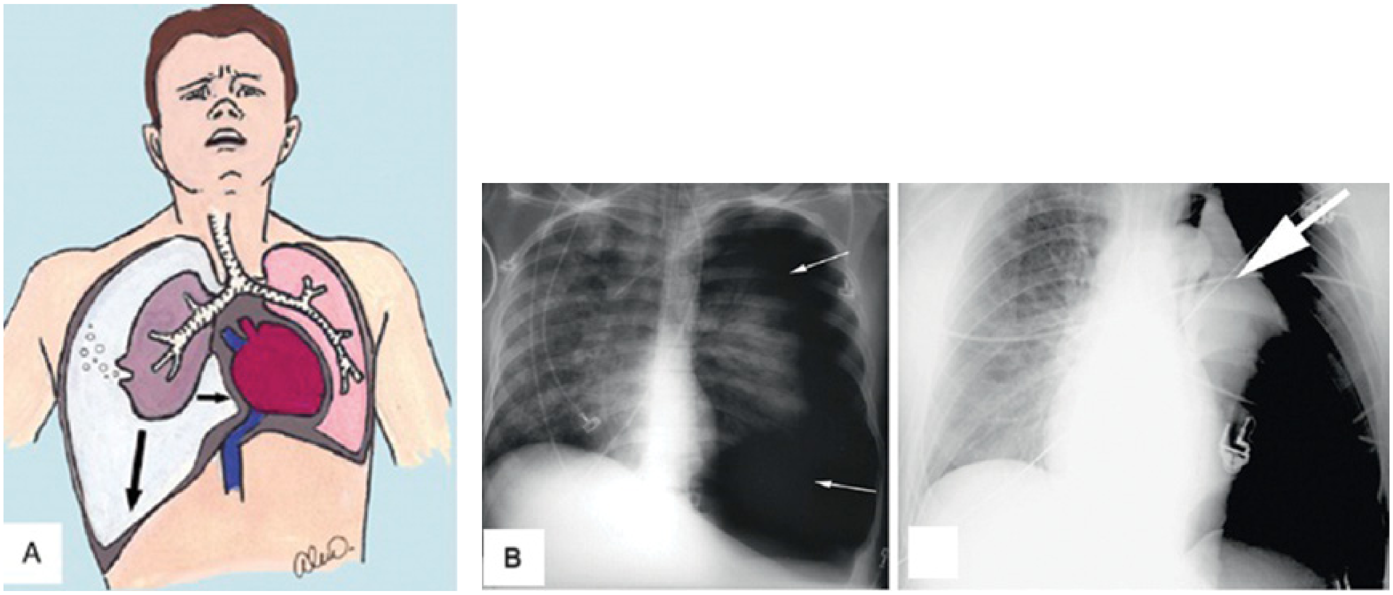


Figure 4.7 A–H

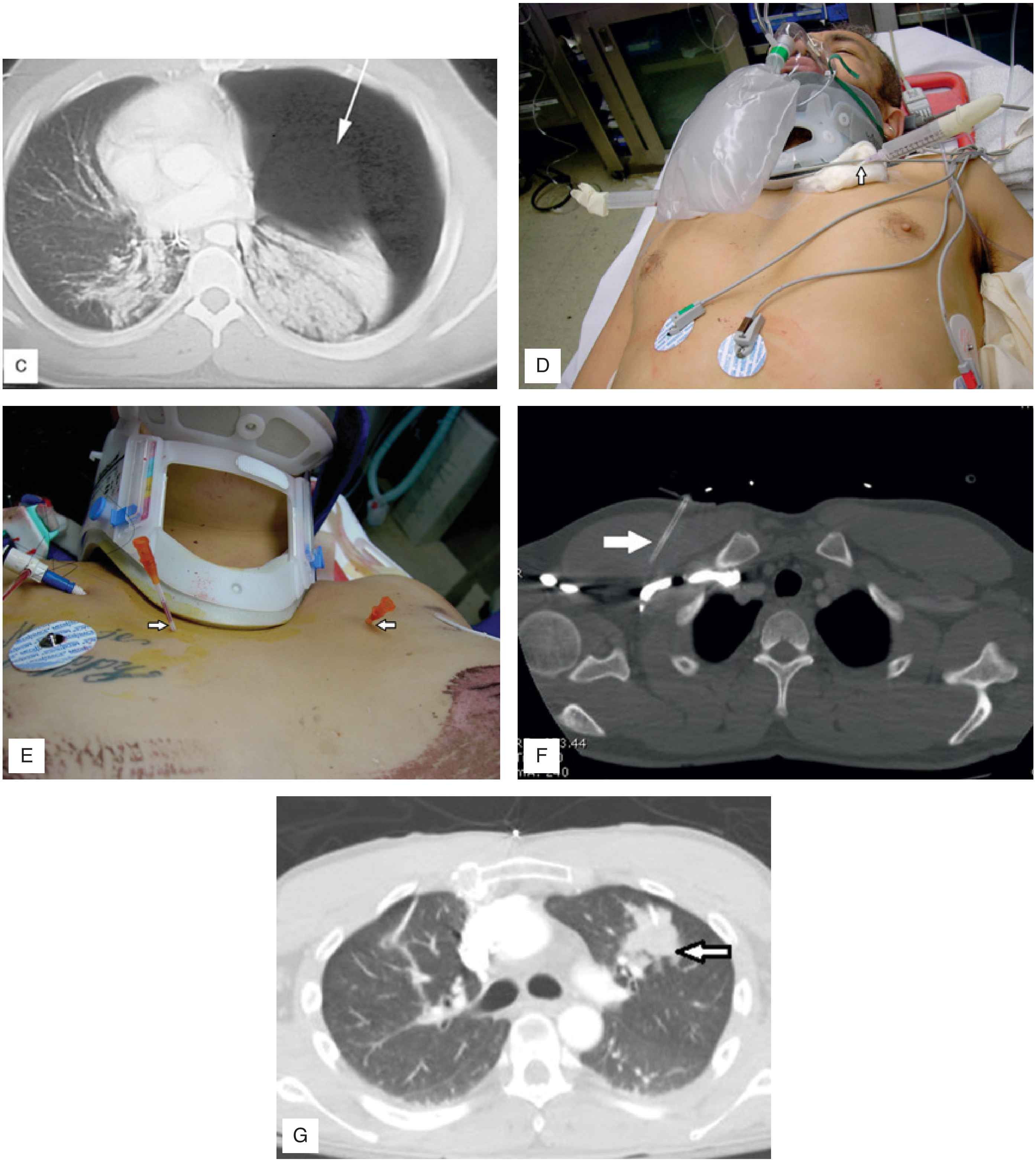


Figure 4.7 A–G Illustration showing mechanism of tension pneumothorax (A). Chest X-rays showing a large tension pneumothorax on the left side, mediastinal shift to the opposite side, and downward displacement of the left hemidiaphragm. Arrows point to tension pneumothorax. (B). CT scan showing tension pneumothorax (arrow) with severe deviation of the heart to the right (C). Photograph showing a thoracostomy needle in place, below the middle of the clavicle (D). Bilateral needle thoracostomies placed prehospital. The catheter on the right side is not in deep enough and is likely outside the pleural cavity. (E). CT scan shows that the thoracostomy needle is located in the subcutaneous tissues, outside the pleural cavity (F). CT scan shows intrapulmonary hematoma secondary to a misplaced needle thoracostomy (G).

Hemothorax

A hemothorax can be due to blunt or penetrating trauma. Large hemothoraces may present with hypovolemia or dyspnea, but small hemothoraces can be asymptomatic. On physical examination, the breath sounds are diminished, there is dullness on percussion, and the affected hemithorax moves poorly. A chest X-ray, preferably in the upright position, may confirm the diagnosis, although many times it cannot distinguish between a hemothorax and intrapulmonary hematoma, contusion, or atelectasis. A supine chest X-ray may miss small hemothoraces. Thoracic ultrasound is a useful investigation in experienced hands, as it can reliably identify hemothorax and distinguish between this diagnosis from atelectasis, pneumonia, and contusion.

Significant hemothoraces can be treated via a thoracostomy tube, inserted at the fourth or fifth intercostal space, in the midaxillary line. A thoracotomy should be considered if the initial thoracostomy tube output exceeds 1,000–1,200 ml of blood or if the patient is hemodynamically unstable. Significant residual hemothorax following thoracostomy tube insertion should be evaluated by means of CT scan and evacuated within three to five days at the latest. Barring contraindications, thrombolytic agents such as tissue plasminogen activator (tPA) or urokinase delivered through the chest tube have resulted in high success rates of evacuation in retained hemothorax as a first line of treatment. In cases selected for operative approach, a video-assisted thoracoscopy (VATS) within three to five days, a maximum of seven days, of diagnosis or a small anterolateral thoracotomy as a last resort should be performed. Delayed evacuation is difficult because of clot organization and inflammation, and it often requires a thoracotomy with decortication.

An undrained significant hemothorax is associated with an increased risk of empyema and may cause respiratory compromise due to fibrosis (Figure 4.8 A–D).

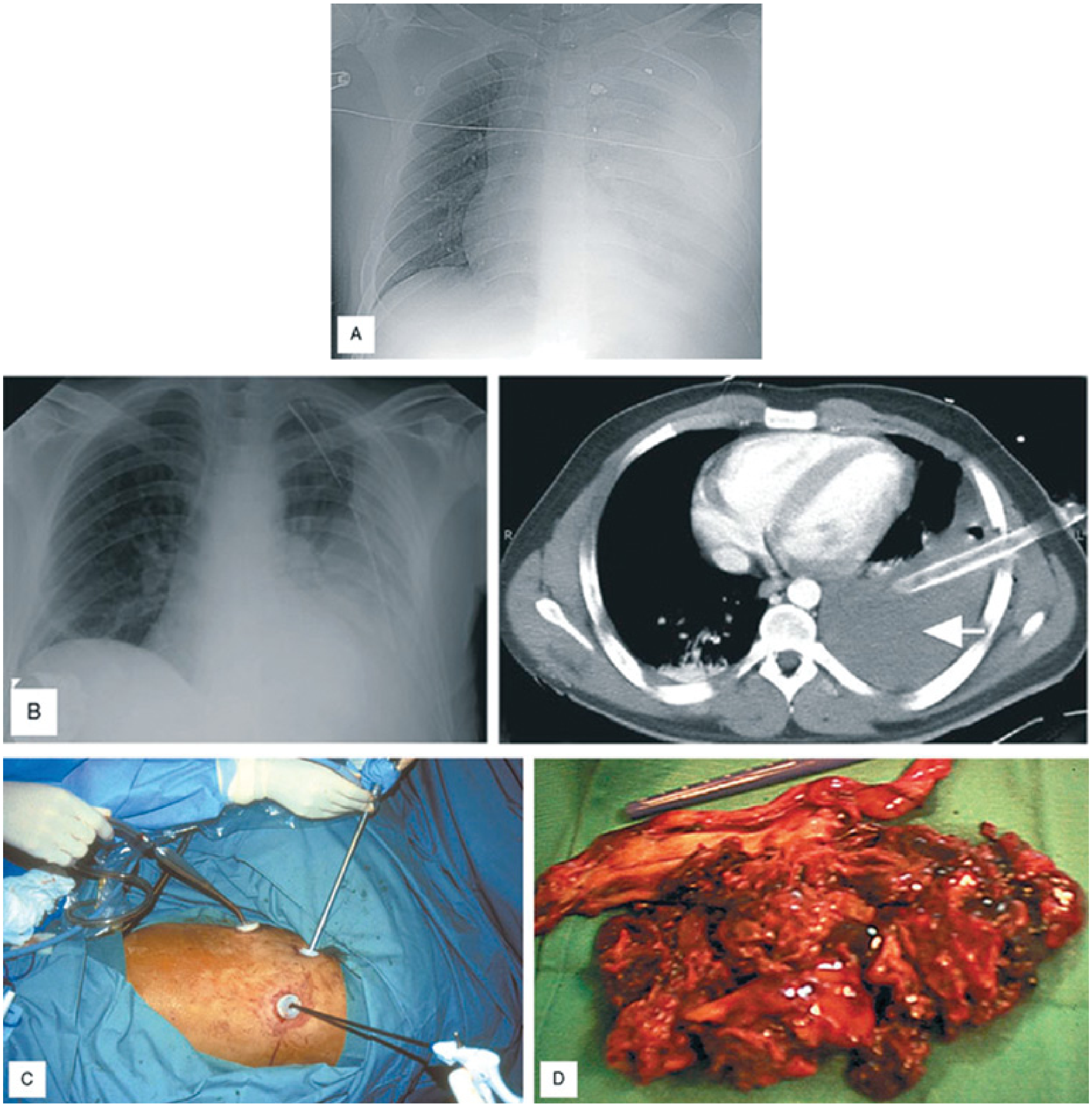


Figure 4.8 A–D Hemothorax. Chest X-ray with extensive opacification of the left hemithorax due to massive hemothorax with mediastinal shift to the opposite side and retained fragments of a missile (A). Gunshot wound to the left chest with suspected “residual hemothorax” on chest X-ray (left) two days after injury. Residual hemothorax is confirmed by CT scan (right) (B). Thoracoscopic evacuation of the residual hemothorax (C). The procedure should be performed within the first five days of injury, before organization of the clot and fibrin encapsulation of the lung. Photograph of material removed during decortication for persistent residual hemothorax and lung entrapment injury (D). Delayed evacuation of a clotted hemothorax is difficult and requires thoracotomy and decortication.

Thoracostomy Tube Insertion

Chest tube can be inserted with an open or a percutaneous dilatational technique. The site and technique of the insertion of the thoracostomy tube are the same for both hemothorax and pneumothorax (see Chapter 19, Thoracostomy Tube Insertion). The trocar technique should be avoided because of the high incidence of serious iatrogenic injuries. The most common complications associated with chest drain insertion include bleeding from the intercostal vessels and injury to the lung parenchyma. Other serious complications include perforation of the heart, the diaphragm, liver, and spleen.

Autotransfusion

Autotransfusion after drainage of a hemothorax should be considered in all patients with significant output or in those with hemodynamic instability or an ongoing blood transfusion requirement. This practice is efficient, safe, and inexpensive. There are several commercially available collection systems, and anticoagulant (1 ml citrate per 10 ml of blood) is advisable but not necessary (Figure 4.9 A,B).

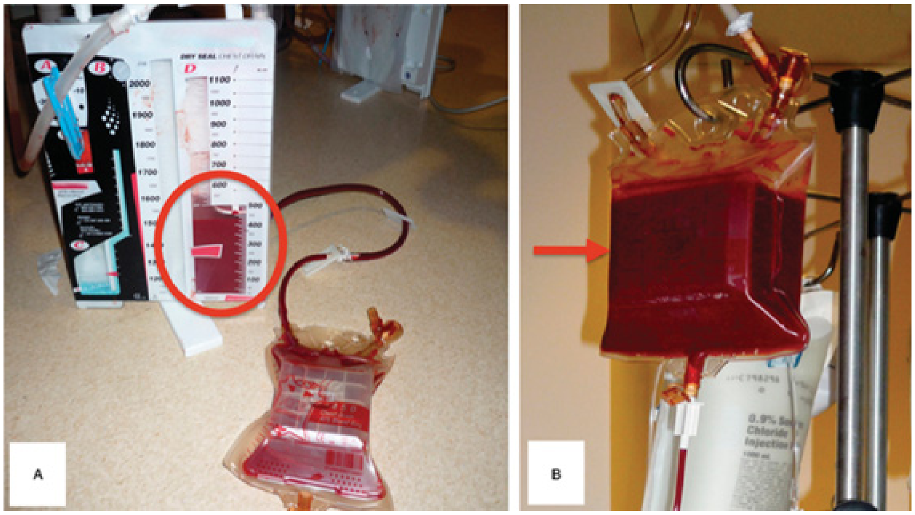


Figure 4.9 A,B Autotransfusion system in hemothorax. The collection chamber of the drainage system (circle) is connected to a negative pressure autotransfusion bag, and the blood is actively sucked into the bag (A). (1 ml of citrate per 10 ml of blood is added to the collection system before drainage.) The collected blood is autotransfused using standard techniques (B).

Lung Contusion

Lung contusion may occur after blunt trauma to the chest, rapid deceleration injuries, or gunshot wounds to the lung. Associated rib fractures are a common finding in adults but less frequent in children. The symptoms may vary from minor chest discomfort to severe dyspnea, massive hemoptysis, and respiratory failure. The treatment is symptomatic, and mechanical ventilation may be necessary. Avoid high tidal volumes and peak inspiratory pressures. High-frequency percussive ventilation (HFPV), airway pressure release ventilation (APRV), or independent lung ventilation (ILV) and occasionally extracorporeal membrane oxygenation (ECMO) may be necessary in patients who do not respond to conventional ventilation.

The radiological diagnosis of a lung contusion is not always reliable with chest X-ray because it has a similar appearance to hemothorax or atelectasis. CT scan delineates lung parenchyma well and provides an accurate diagnosis. The contusion usually improves and resolves within a few days. Failure to improve radiologically should raise the suspicion of pneumonia or residual hemothorax (Figure 4.10 A,B, Figure 4.11 A–C, Figure 4.12 A–D).

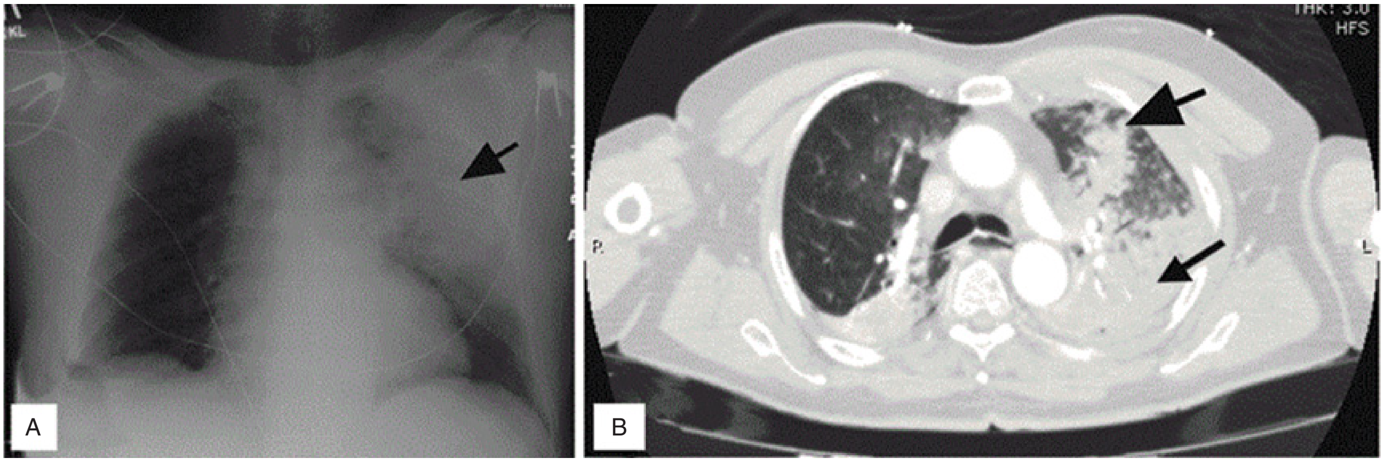


Figure 4.10 A,B Lung contusion: chest X-ray with large opacification in the left lung, highly suspicious for lung contusion (A). Chest CT scan confirms the presence of lung contusion (B).

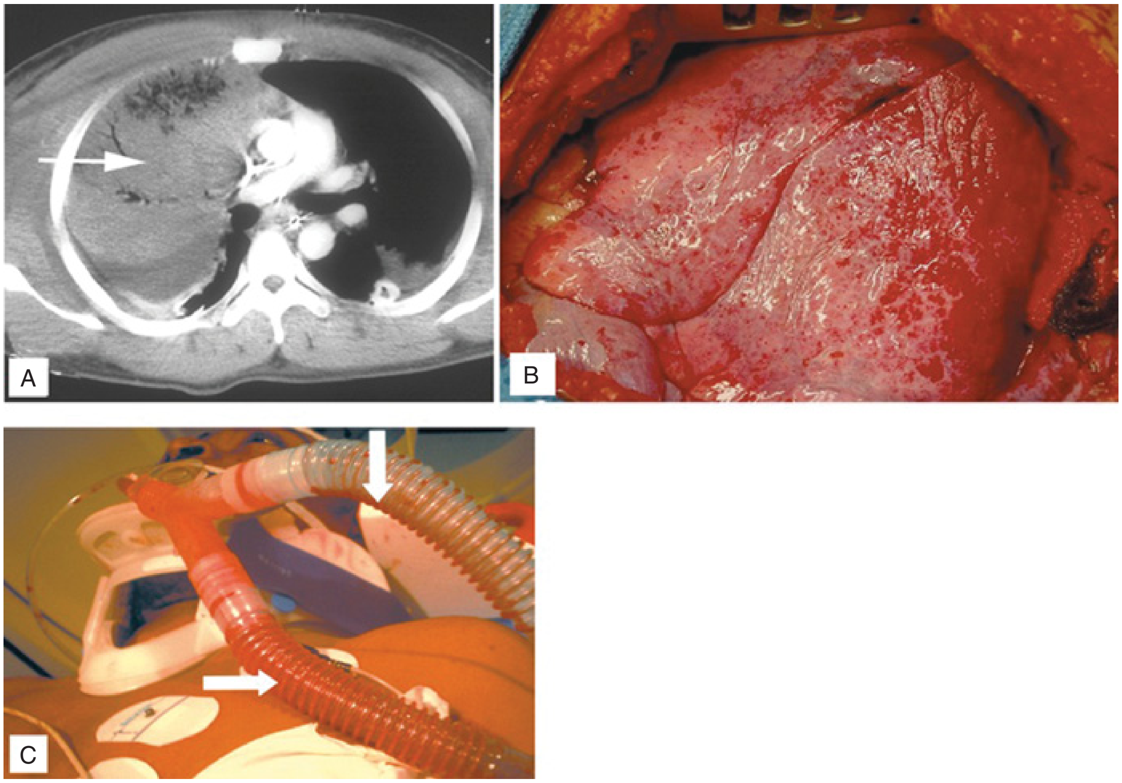


Figure 4.11 A–C Lung contusion: CT scan appearance of a large contusion (arrow; A). Intraoperative appearance of lung contusion (B). Bronchial bleeding in respiratory tubing is a common finding in severe lung contusions (C). Flooding of the normal lung may result in respiratory failure. Double-lumen endotracheal tube and independent lung ventilation should be considered.

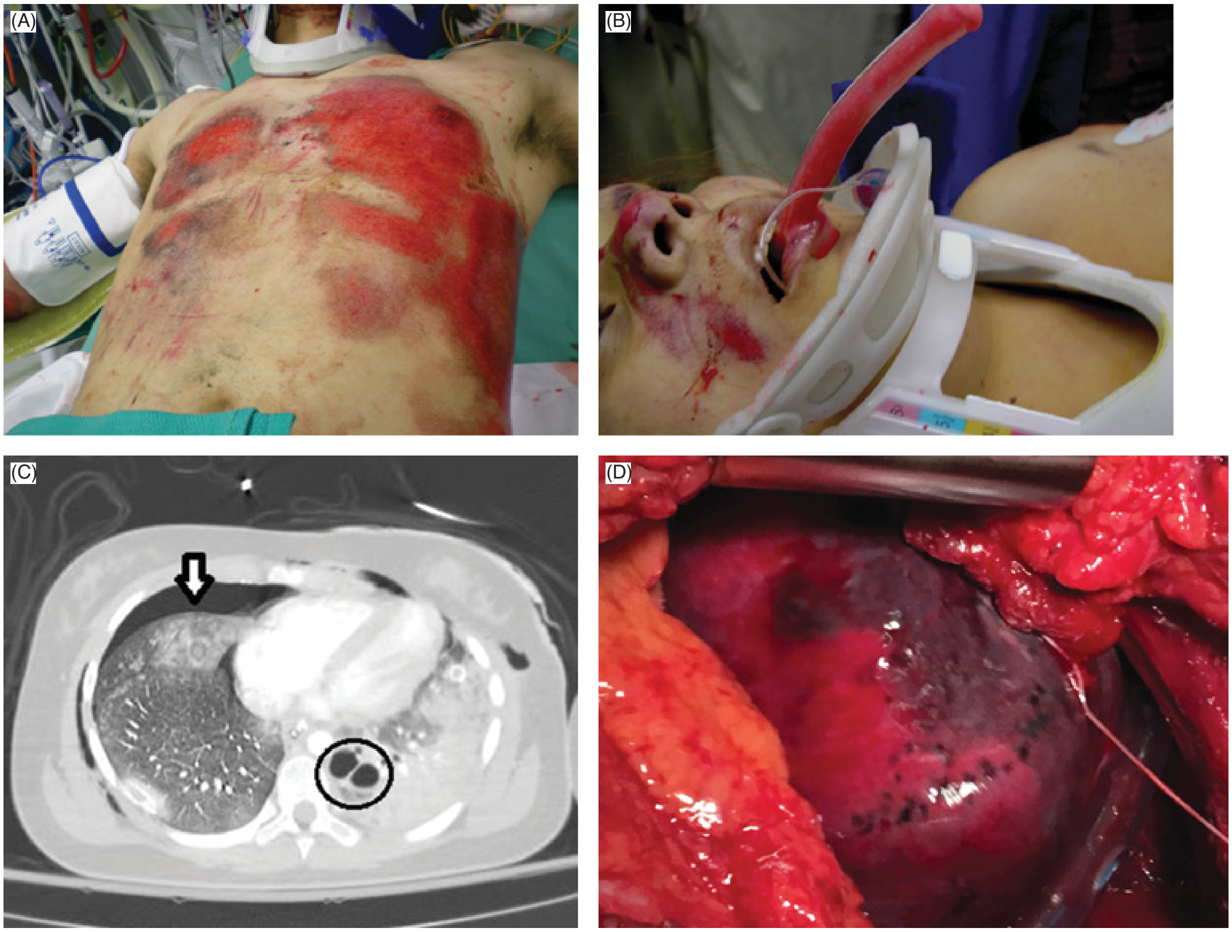


Figure 4.12 A–D Lung contusion: Auto versus pedestrian injury with chest trauma, admitted in severe respiratory distress requiring endotracheal intubation (A). Blood in the endotracheal tube indicates severe lung contusion (B). CT scan showing severe bilateral lung contusions, right pneumothorax (arrow), and lung lacerations (circle; C). Patient required emergency thoracotomy for bleeding. Intraoperative appearance of lung contusion (D).

Subcutaneous Emphysema

Subcutaneous emphysema may be secondary to a pneumothorax or aerodigestive tract perforation. A poorly placed thoracostomy tube, with a fenestration outside the pleural cavity, may also result in extensive emphysema. The first step in evaluating the cause of the emphysema is to check the position of the thoracostomy tube. For massive, unexplained emphysema, endoscopy should be performed to evaluate the aerodigestive tract. Subcutaneous emphysema rarely causes symptoms, and the treatment is directed toward the underlying cause (Figure 4.13, Figure 4.14 A–C).

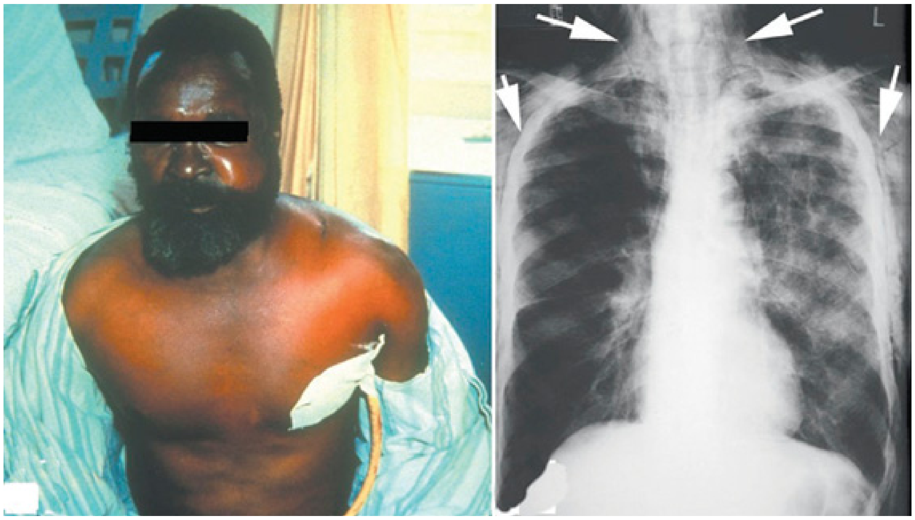


Figure 4.13 Subcutaneous emphysema. Patient and chest X-ray with extensive subcutaneous emphysema in the face, neck, and chest wall.

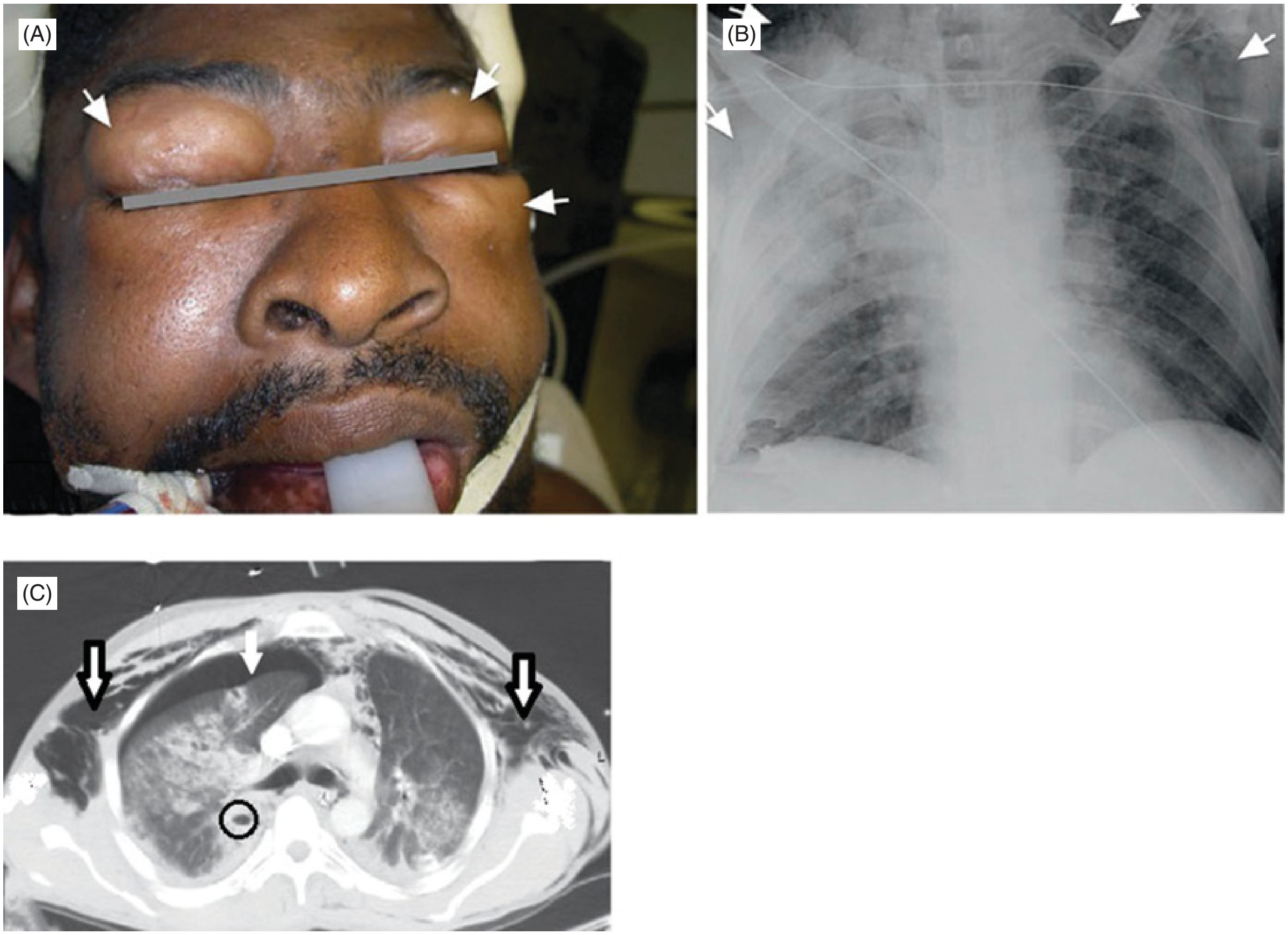


Figure 4.14 A–C Patient with severe blunt chest trauma presenting with extensive subcutaneous emphysema involving the face and neck (A). Chest X-ray showing extensive subcutaneous emphysema in the chest wall (arrows) and a right lung contusion (B). CT scan shows extensive bilateral subcutaneous emphysema (black and white arrows), lung contusions, and a right pneumothorax (white arrow). A small lung laceration is shown like a cystic lesion (circle; C).

Penetrating Cardiac Injury

More than 80% of patients with penetrating cardiac injuries die at the scene. For those who reach the hospital alive, immediate diagnosis and operation are critical for survival.

Clinically the patient is restless, and the inexperienced physician often misdiagnoses the agitation as alcohol or drug intoxication. The victim is almost always in shock, although in cases with small cardiac wounds and short prehospital times, the initial blood pressure may be normal. Beck's triad (hypotension, distant cardiac sounds, distended neck veins) is found in about 90% of cases with tamponade. Pulsus paradoxus is rarely found in acute tamponade.

Stab wounds usually involve the right ventricle, and the prognosis is fairly good, with a hospital survival of about 65%. Bullet injuries usually involve multiple cardiac chambers and the prognosis is poor, with an overall hospital survival of about 15%. High-velocity bullets cause massive injury and are nearly always fatal.

The outcome of penetrating cardiac trauma depends on many factors: short prehospital transport times, an experienced trauma team, low-velocity injuries, right ventricular injuries, and the presence of cardiac tamponade are favorable factors for survival (Figure 4.15, Figure 4.16 A,B, Figure 4.17 A–C).

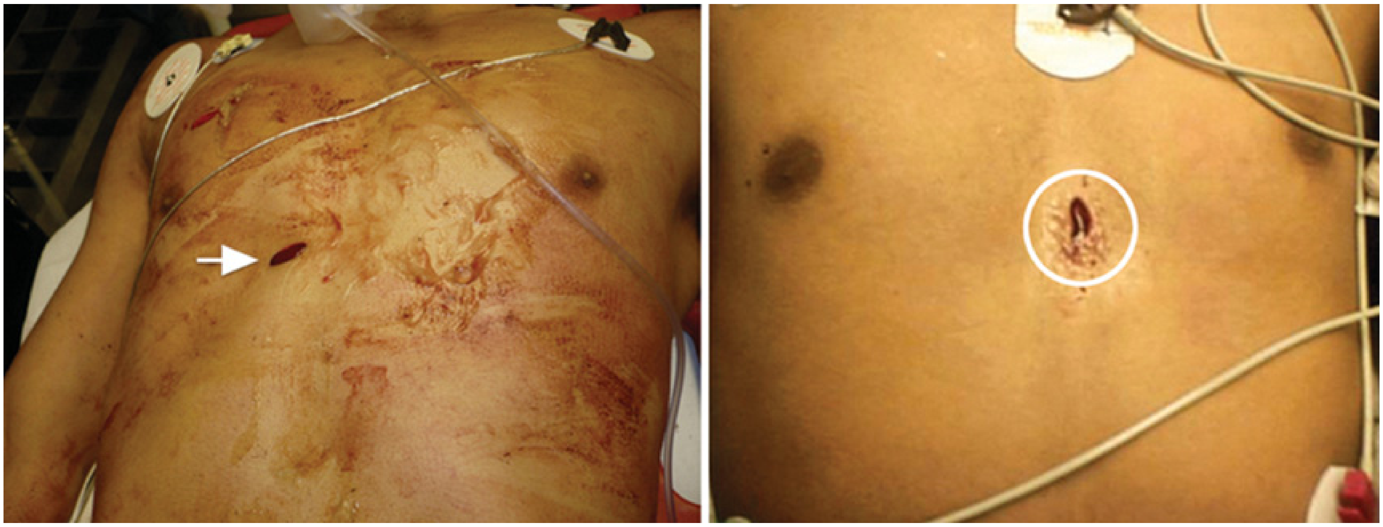


Figure 4.15 Patients with precordial penetrating wounds. Every penetrating injury to the chest, especially in the presence of hypotension, should be considered as a cardiac injury until proven otherwise.

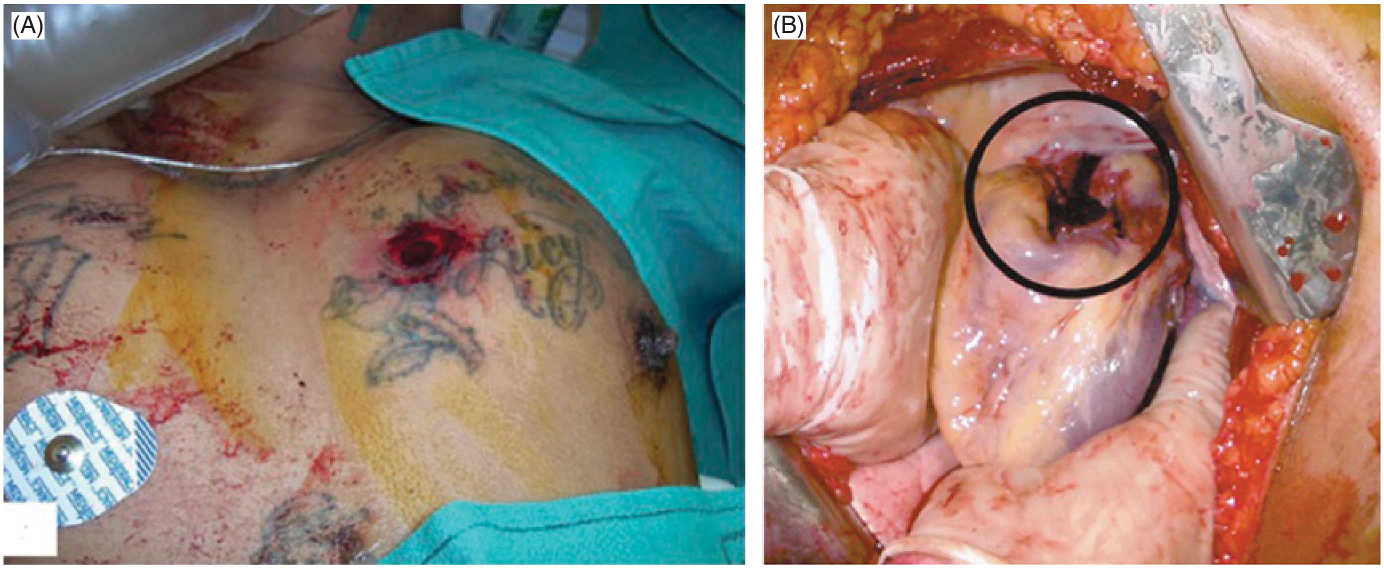


Figure 4.16 A,B Cardiac wounds. Patient with precordial gunshot wound. In these cases, especially in the presence of hypotension, a cardiac injury should be suspected (A). Cardiac injury explored through sternotomy demonstrating a large wound in the right ventricle (B).

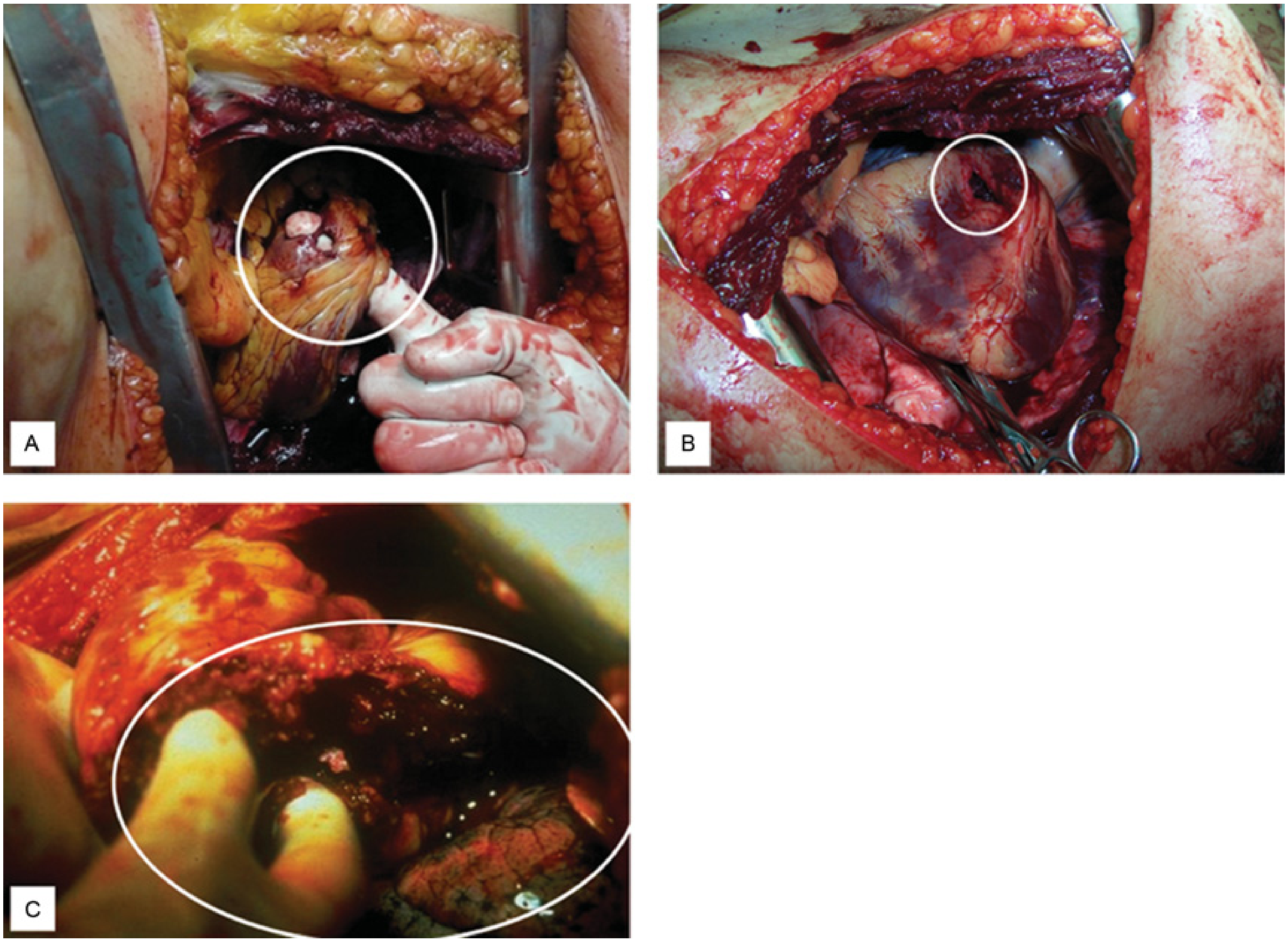


Figure 4.17 A–C Photographs of low-velocity bullet injuries to the heart (A,B). Photograph of a massive trauma to the heart from a high-velocity bullet injury (C).

Diagnosis of Cardiac Injury

The diagnosis of penetrating cardiac injury is usually clinical and can be confirmed by pericardial ultrasound as part of the FAST exam in the emergency department. A chest film may be helpful in about half the cases with cardiac trauma. Radiologic signs suggestive of cardiac trauma include an enlarged cardiac shadow, a widened upper mediastinum (due to a dilated superior vena cava), and pneumopericardium (a sign of pericardial violation). An EKG may be consistent with injury in about 30% of cases with cardiac injury. It may show low-voltage QRS complexes, elevated ST segments, inverted T waves, electrical alternans, and other nonspecific findings (Figure 4.18, Figure 4.19 A,B, Figure 4.20 A,B, Figure 4.21, Figure 4.22 A,B).

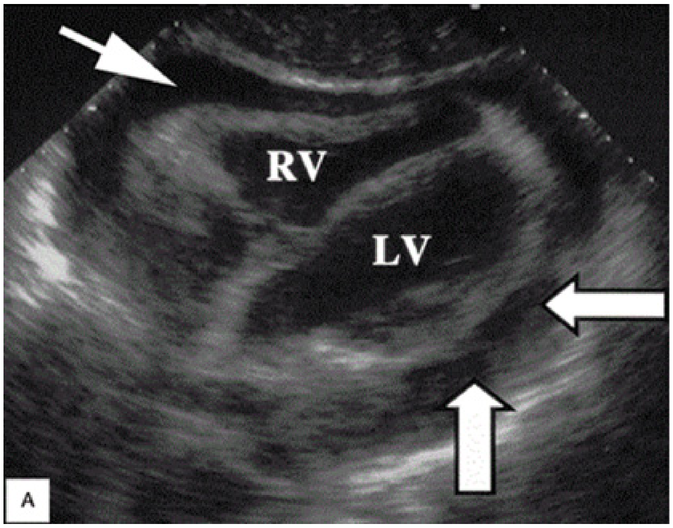


Figure 4.18 Investigations for cardiac injury. FAST showing a circumferential pericardial effusion (arrows) diagnostic of cardiac tamponade (RV = right ventricle, LV = left ventricle).

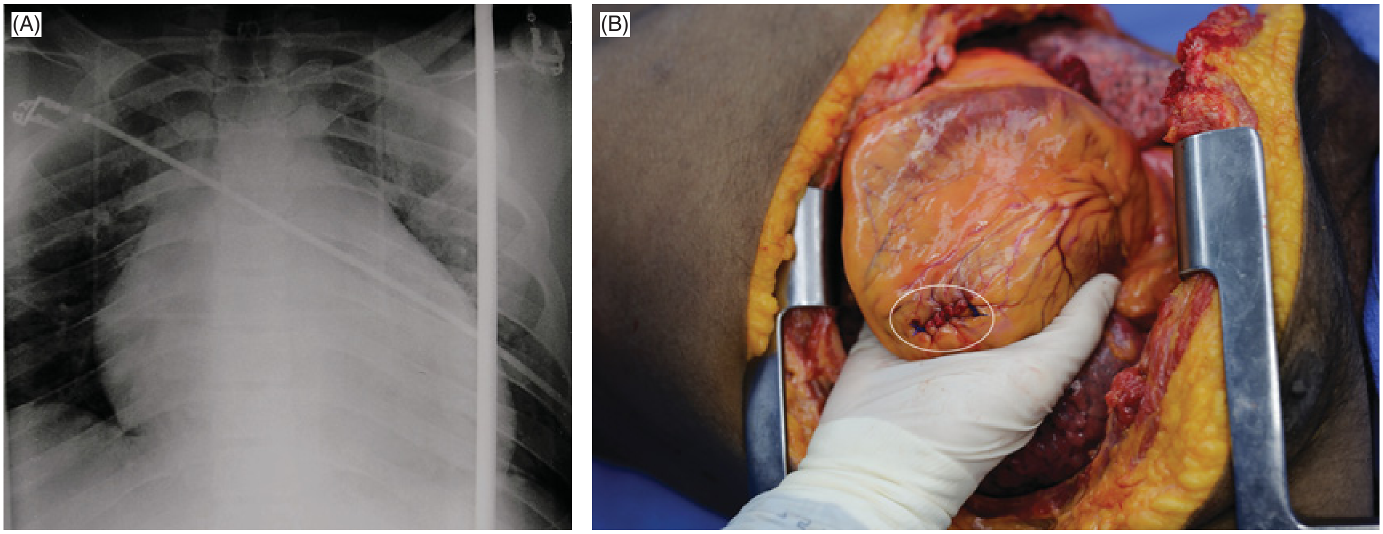


Figure 4.19 A,B Patient with stab wound to the anterior chest. Chest X-ray showing enlargement of the cardiac shadow suggestive of cardiac tamponade (A). Emergency thoracotomy revealed an injury at the apex of the heart, which was sutured (circle; B).

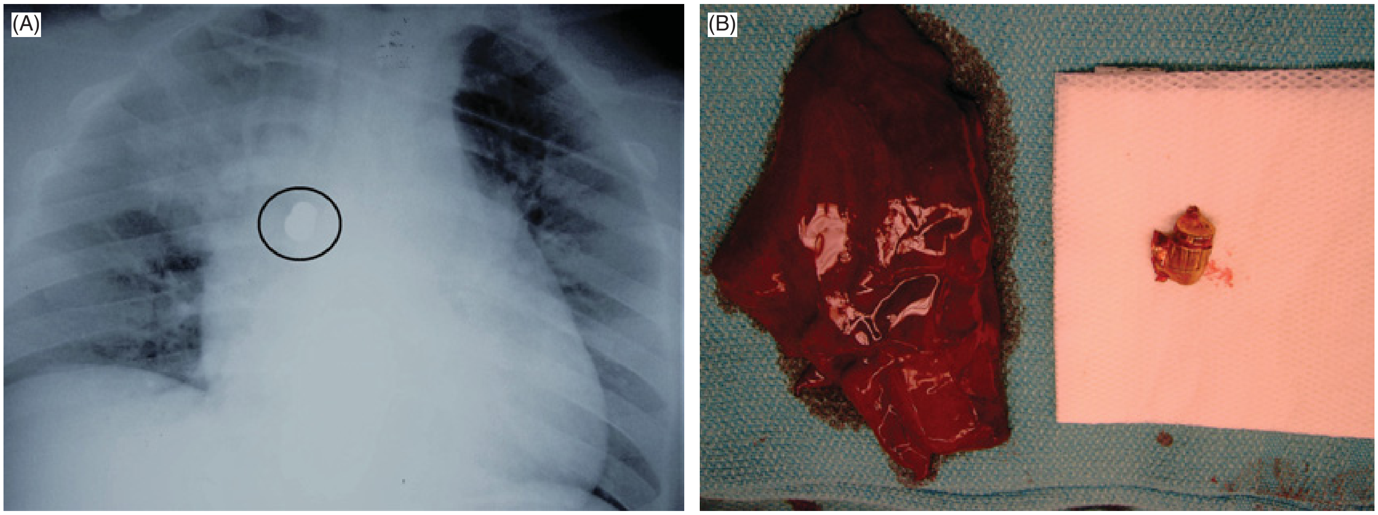


Figure 4.20 A,B Patient with a gunshot wound to the left chest. Chest X-ray showing a bullet in the mediastinum and an enlarged cardiac shadow, suggestive of tamponade (A). Emergency operation revealed a cardiac tamponade with a large clot and an injury to the right ventricle. A bullet was removed from the pericardium (B).

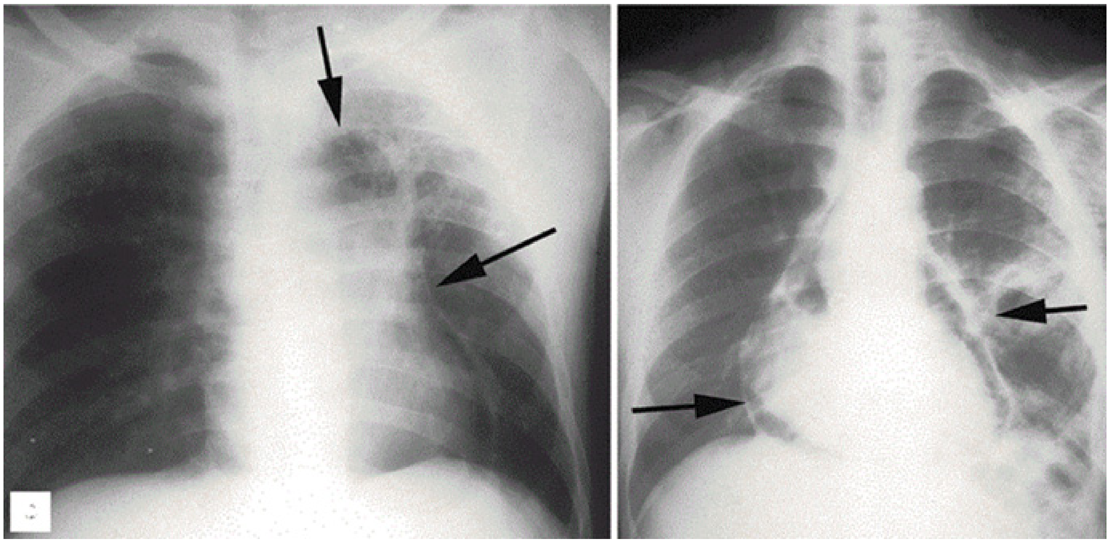


Figure 4.21 Chest X-rays depicting pneumopericardium (arrows), diagnostic of pericardial violation.

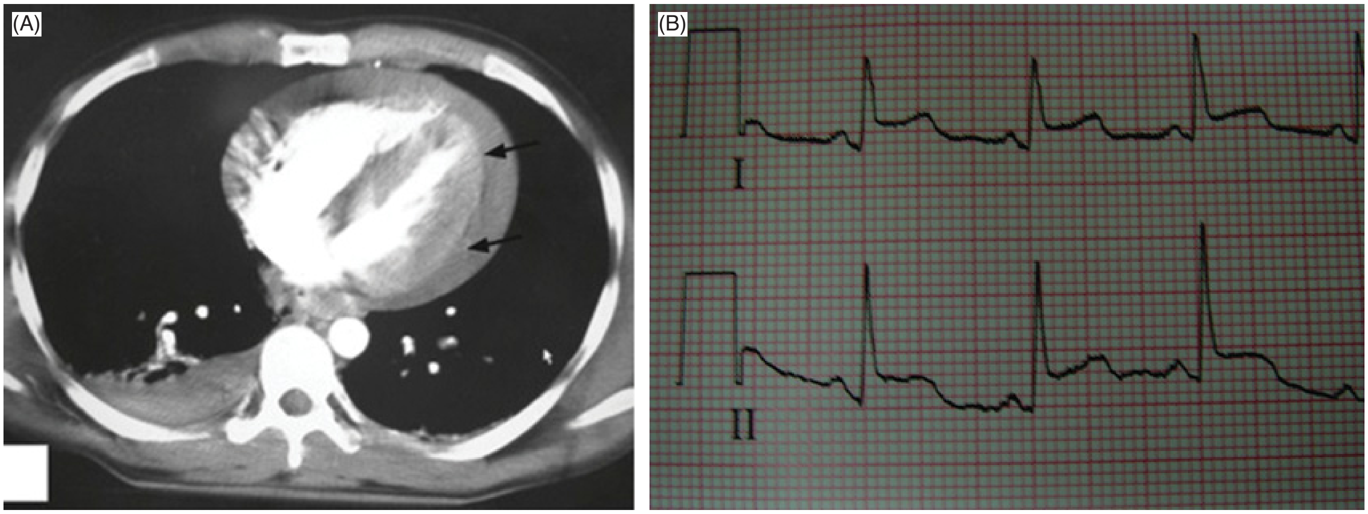


Figure 4.22 A,B Patient with a stab wound to the chest, hemodynamically stable, FAST exam showed small pericardial effusion. CT scan showing a moderate pericardial effusion (arrows) (A). EKG showing ST elevation (B). During operation, there was a partial thickness perforation of the right ventricle.

The subxiphoid window is a major invasive procedure and has a very limited or no role in the diagnosis of cardiac tamponade. Similarly, pericardiocentesis has little or no place in a modern trauma center. The blood in the pericardial sac usually clots, and this results in high incidence of false-negative pericardiocentesis.

In addition, there is a risk of injury to the myocardium and coronary vessels, especially in the absence of tamponade. It is a major invasive diagnostic procedure and has a limited role in a modern trauma center (Figure 4.23 A,B).

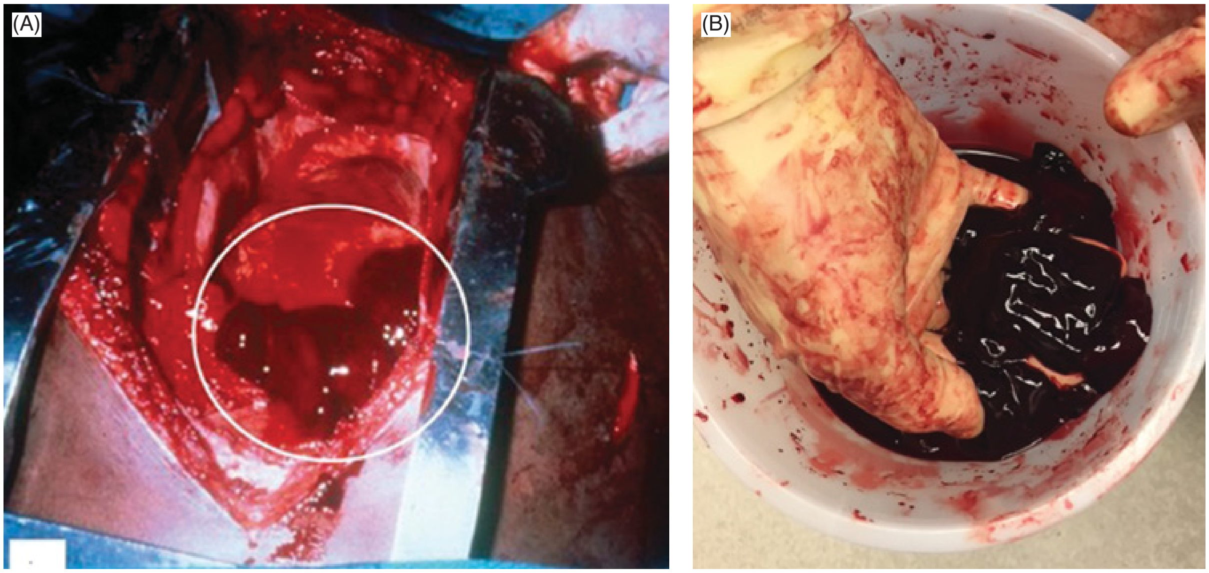


Figure 4.23 A,B Intraoperative photograph of a clot within the pericardial sac (A). Evacuated clot in a patient with a cardiac tamponade (B). A pericardiocentesis would have been falsely negative.

Retained Cardiac Missiles

The diagnosis of retained cardiac missile is suspected on the chest X-ray and confirmed by echocardiogram or CT scan. All large missiles diagnosed at the acute stage should be removed because of the risk of delayed hemorrhage, embolization, false aneurysm, and endocarditis. Similarly, endocardiac missiles should be removed because of the risk of embolization. Removal by interventional cardiology is the preferred method. Small pellets or retained missiles in the myocardium that have been diagnosed long after the injury and are asymptomatic do not need routine removal. Echocardiography evaluation is essential in determining if a retained missile needs removal (Figure 4.24, Figure 4.25 A–C).

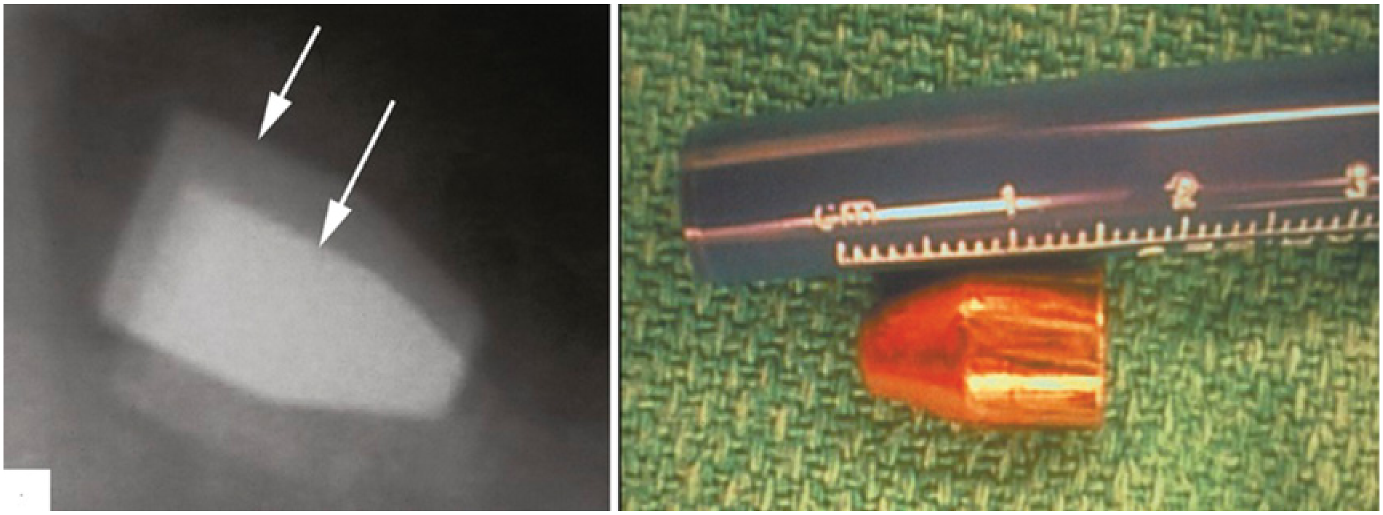


Figure 4.24 Chest X-ray showing a bullet lodged in the myocardium. The double shadow (arrows) of the bullet is diagnostic of contact of the foreign object with the beating heart (left). The bullet was removed operatively (right).

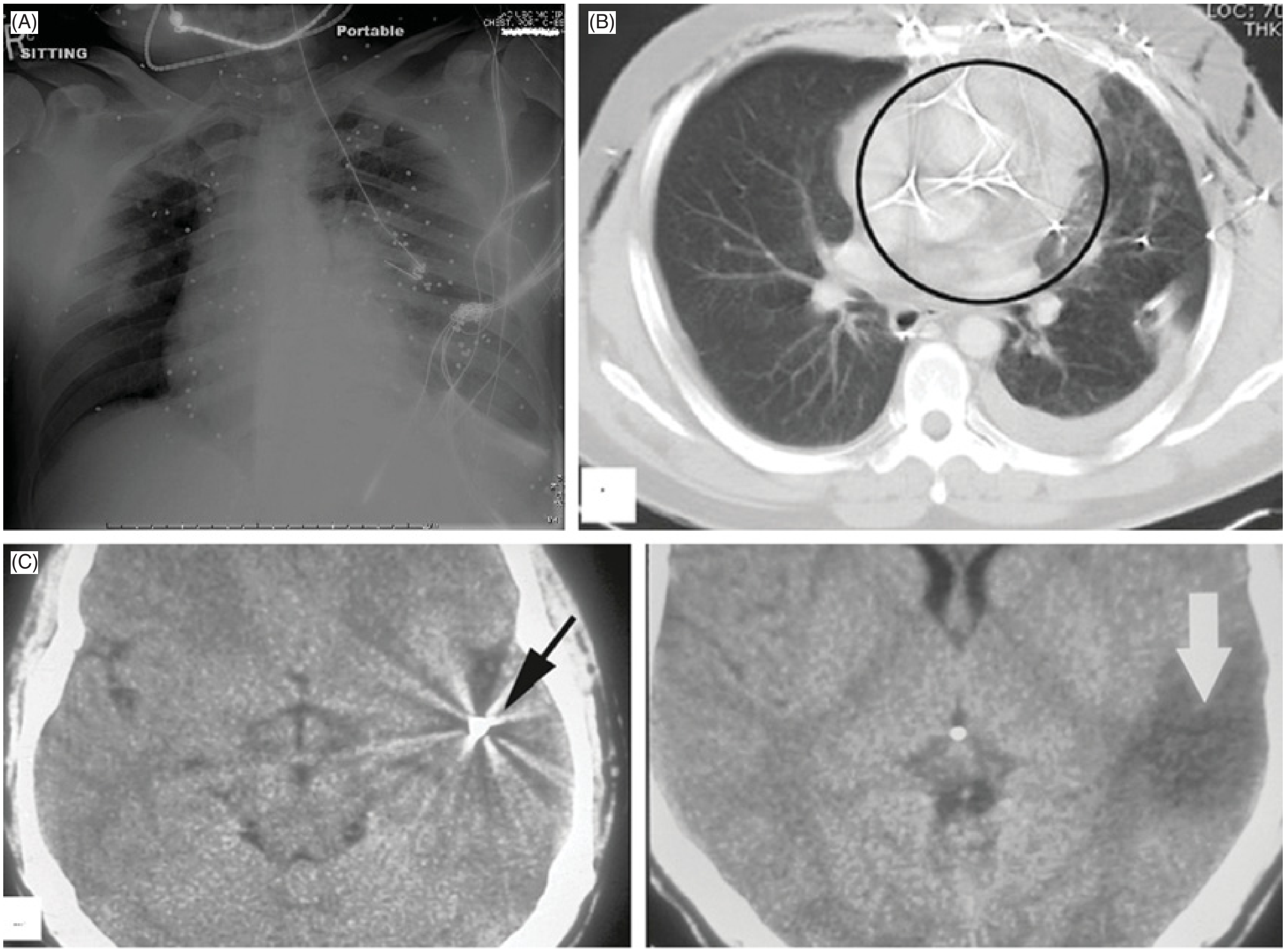


Figure 4.25 A–C Chest radiograph showing multiple pellets in the myocardium and the heart following a shotgun injury (A). CT scan showing multiple pellets in the myocardium and the cardiac chambers (B). Embolization of one of the pellets in the brain resulted in anemic brain infarction (arrows) (C).

Emergency Department Thoracotomy

Patients with cardiac arrest or imminent cardiac arrest in the emergency department should be managed with an immediate left anterolateral thoracotomy, through the fourth or fifth intercostal space (under the nipple in males or the inframammary crease in females). A lower incision may injure the diaphragm, while a higher incision does not provide a good exposure of the heart.

The pericardium is opened longitudinally to avoid injury to the phrenic nerve, and the clot is evacuated. The cardiac wound is repaired by suturing or, in the absence of available suture, with stapling. A Foley catheter balloon may be useful in achieving temporary control of bleeding; however, care should be taken not to exert undue force on the balloon, as this can further damage the myocardium and enlarge the injury. In the presence of cardiac arrest, the aorta is cross-clamped just above the diaphragm, and direct cardiac massage is performed. Sodium bicarbonate and calcium should be administered intravenously, preferably through a central venous line. Intravenous or intracardiac epinephrine may be administered once the heart is full; however, use of this medication prior to resuscitation reduces the chance of successful resuscitation. Internal defibrillation may be used when indicated, and internal cardiac pacing may be useful in cases that do not respond to conventional treatment. If cardiac activity returns, the operation is completed in the operating room. Details of the operation are shown in Chapter 20, Emergency Room Resuscitative Thoracotomy (Figure 4.26 A–G).

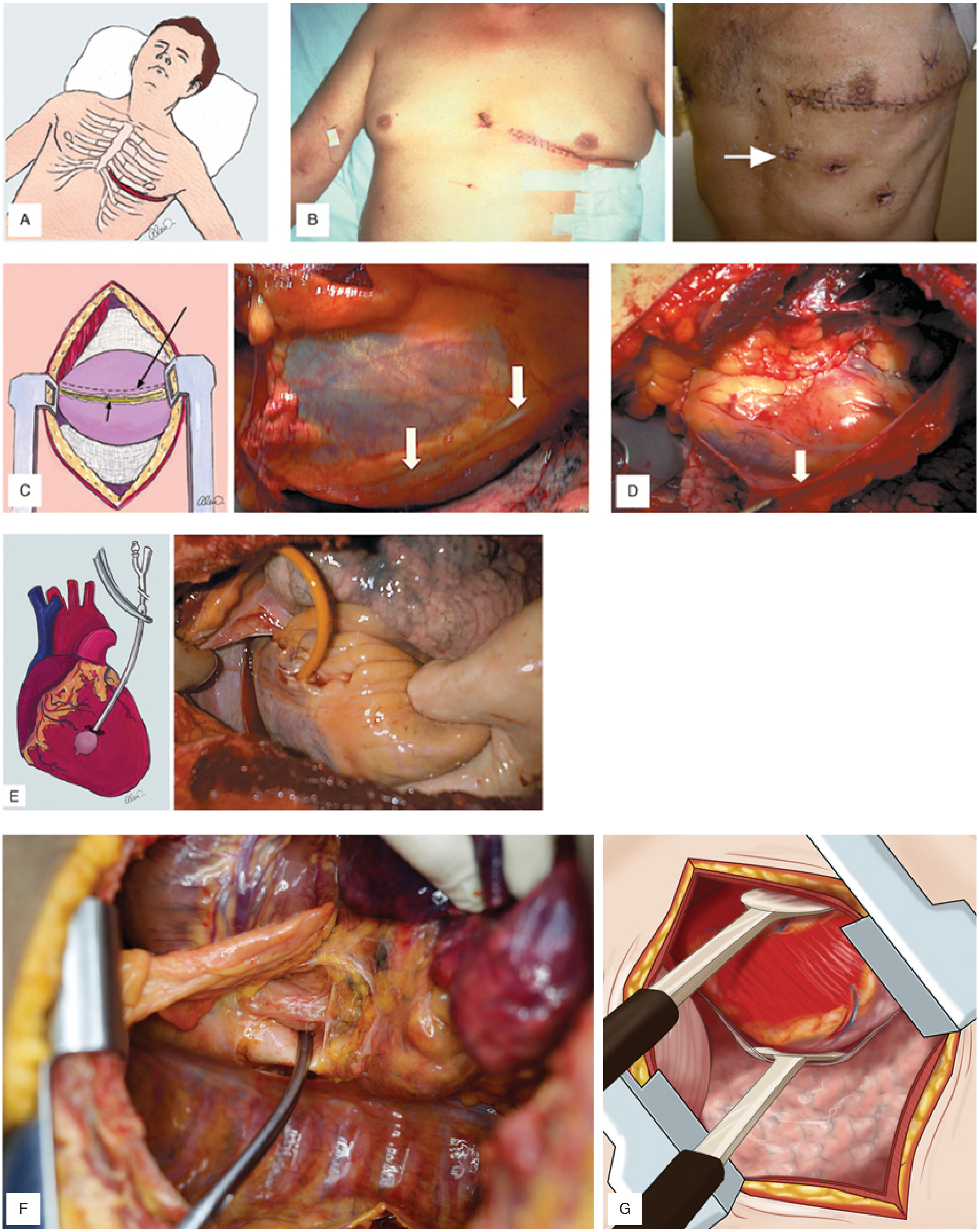


Figure 4.26 A–G Emergency room resuscitative thoracotomy for injury to the heart. Illustration of the incision for a resuscitative emergency department left anterolateral thoracotomy (A). Photographs showing incisions for resuscitative thoracotomy, in a female and a male patient (B). Illustration and photo of the pericardium at thoracotomy. The phrenic nerve is seen on the lateral aspect of the pericardium. The pericardium should be opened above the nerve (C). The pericardium is opened and the heart exposed (D). Illustration and intraoperative photograph showing the use of a Foley catheter for temporary bleeding control from a cardiac wound (E). Photograph of a cross-clamping of the thoracic aorta. The clamp should be applied about 3–4 cm above the diaphragm (F). Internal cardiac defibrillation during emergency room resuscitative thoracotomy (G).

The indications for emergency department thoracotomy are controversial. The ideal candidate is a penetrating chest trauma patient, with imminent or established cardiac arrest. However, we recommend liberal indications, which include cardiac arrest or imminent cardiac arrest due to both penetrating and blunt trauma in any body area. Although with this policy the survival is very low, there are cases with unexpected survival with good functional outcomes. In addition, in patients who survive with brain death, the possibility of organ and tissue donation is another outcome, and this approach provides an opportunity for the family to consider this option.

Late Sequelae of Penetrating Cardiac Injuries

Late posttraumatic cardiac sequelae include anatomical defects (pericardial effusion, atrial or ventricular septal defects, valvular or papillary muscle lesions) and functional abnormalities (dyskinesia, hypokinesia). All survivors should be evaluated early and late postoperatively, clinically, and by means of EKG and echocardiography. Many abnormalities may not manifest early, and a late cardiac evaluation performed a few weeks post injury is essential (Figure 4.27 A-B).

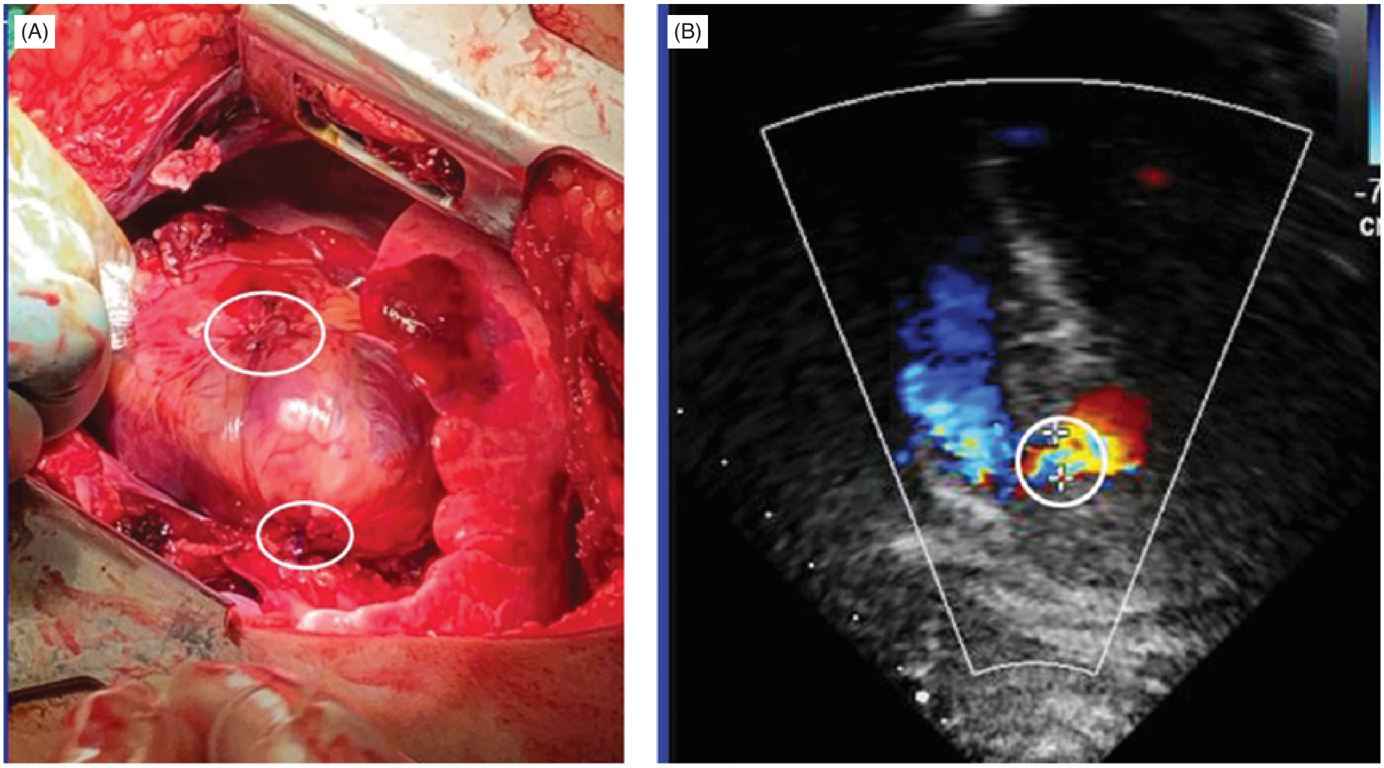


Figure 4.27 A-B Through and through gunshot wound of the heart (A). Postoperative echocardiogram demonstrates a ventricular septal defect near the apex (B).

Blunt Cardiac Trauma

There are no uniform criteria for the diagnosis of blunt cardiac trauma. Many patients are asymptomatic, with only EKG changes or troponin elevations. Others may present with tachycardia, arrhythmia, or cardiogenic shock. All patients with a suspicious mechanism of injury, a fractured sternum, or anterior rib fractures should be evaluated by means of FAST, EKG, and troponin levels. If these tests are normal, no further investigation is needed. If the EKG is abnormal or the troponin levels are elevated, the patient should be monitored closely and evaluated with formal echocardiogram. Symptomatic patients may need inotropes or antiarrhythmic treatment.

Cardiac rupture may result from major anteroposterior chest compression, rapid deceleration, perforation by fractured ribs or sternum, or massive sudden crushing forces on the abdomen. Blunt cardiac rupture is diagnosed at autopsy in about 30% of fatal blunt trauma. Patients with blunt cardiac rupture rarely reach the hospital alive. These patients are in severe shock, and the diagnosis can be confirmed by FAST or during an emergency department thoracotomy. Most ruptures involve the right heart. In these cases, immediate thoracotomy with cardiac repair should be performed (Figure 4.28, Figure 4.29 A–C, Figure 4.30).

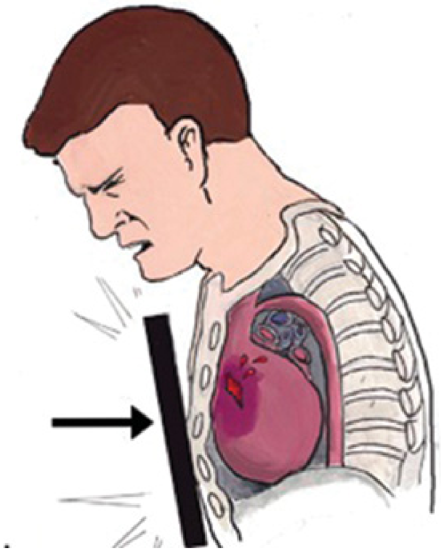


Figure 4.28 Illustration of the mechanism of blunt cardiac injury from steering wheel.

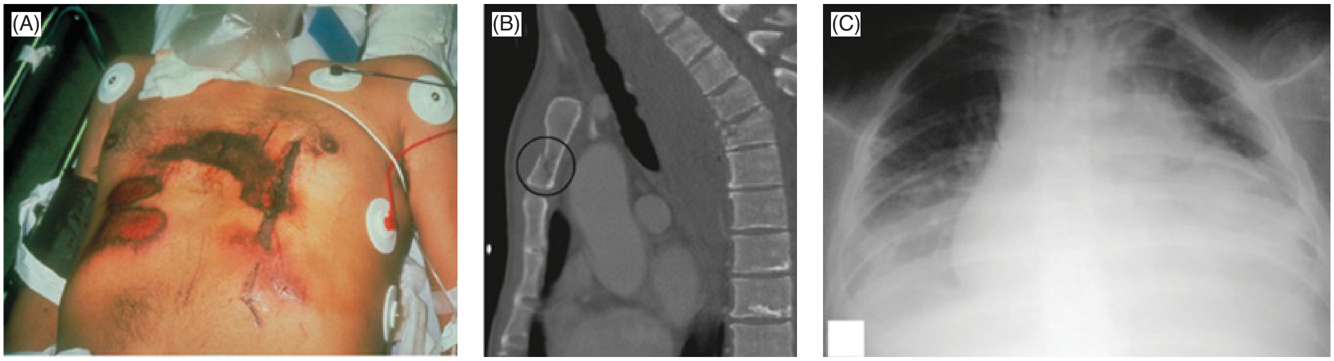


Figure 4.29 A–C Photograph of blunt chest trauma to the anterior chest. This patient arrived in ventricular tachycardia (A). CT scan showing sternal fracture (circle). This injury is often associated with cardiac trauma (B). These patients should be evaluated by EKG and serial troponin levels. Chest X-ray shows delayed pericardial effusion following myocardial contusion due to blunt trauma (C).

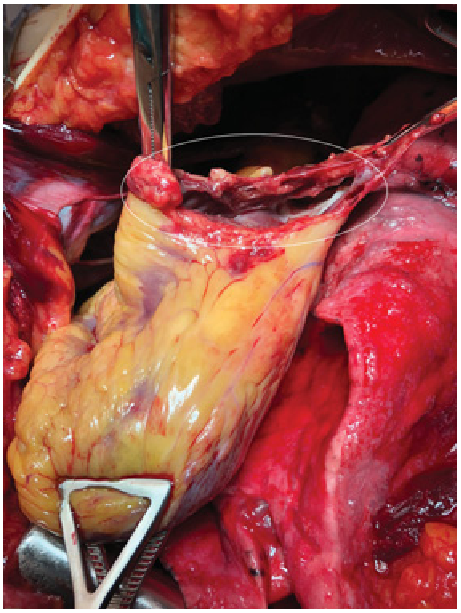


Figure 4.30 Photograph of cardiac rupture (right atrium) following blunt trauma.

Blunt Thoracic Aortic Injury

Blunt thoracic aortic injury usually occurs after deceleration injuries, such as high-speed traffic collisions or falls from heights. In about 93% of cases, the rupture occurs just distal to the left subclavian artery (Figure 4.31, Figure 4.32 A,B), and

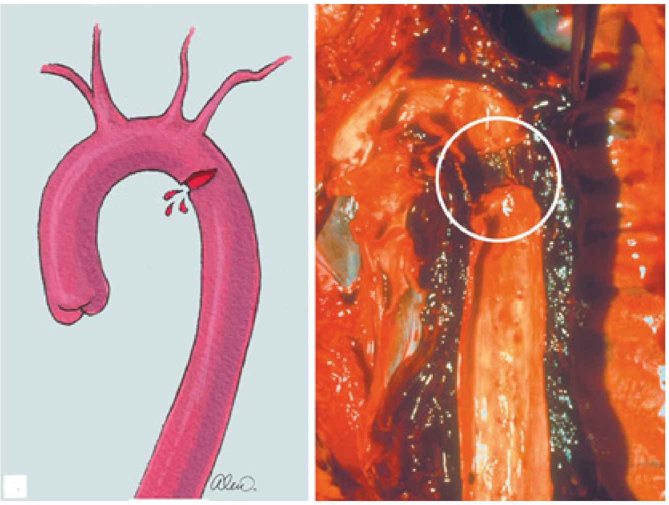


Figure 4.31 Illustration and autopsy specimen of the typical site of blunt aortic rupture, distal to the left subclavian artery.

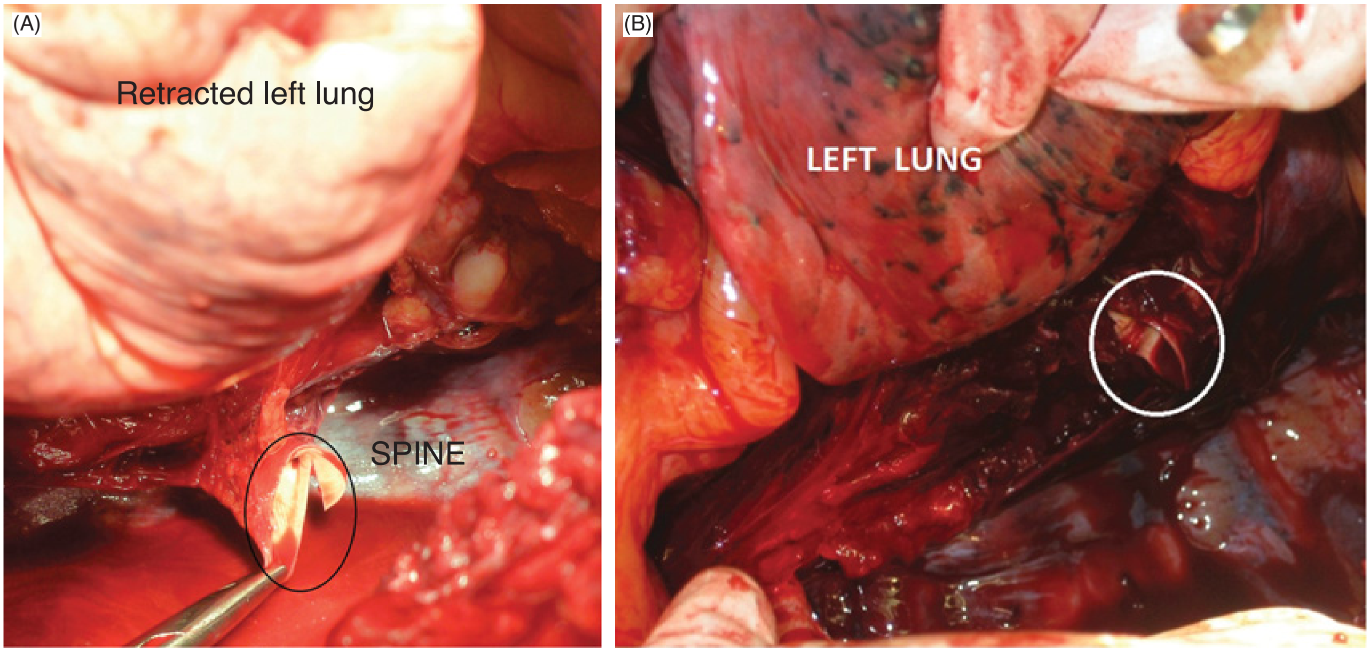


Figure 4.32 A,B Intraoperative photograph of a transected thoracic aorta, distal to the left subclavian artery, found at emergency room thoracotomies.

in about 7% the rupture occurs in the ascending aorta. About 34% of all fatalities due to blunt trauma have a rupture of the thoracic aorta at autopsy. Most of the victims die at the scene, with only about 20% of patients reaching hospital care. The diagnosis is based on the history of the injury and suspicious chest X-ray findings. Radiological findings suggestive of aortic rupture include a widened upper mediastinum, left apical pleural cap, obliteration of the aortic knob, and deviation of the nasogastric tube or the left main bronchus to the right. However, in many cases of aortic rupture, the chest X-ray may be normal. All patients with a suspicious mechanism of injury should be evaluated by means of CTA after stabilization (Figure 4.33, Figure 4.34 A,B, Figure 4.35). Diagnostic aortography should be reserved for patients requiring angiography for another reason (e.g., angioembolization for pelvic fracture) or cases when the CTA is not definitive. However, therapeutic aortography with endovascular stent-graft aortic repair has rapidly evolved and has become the standard of care in aortic

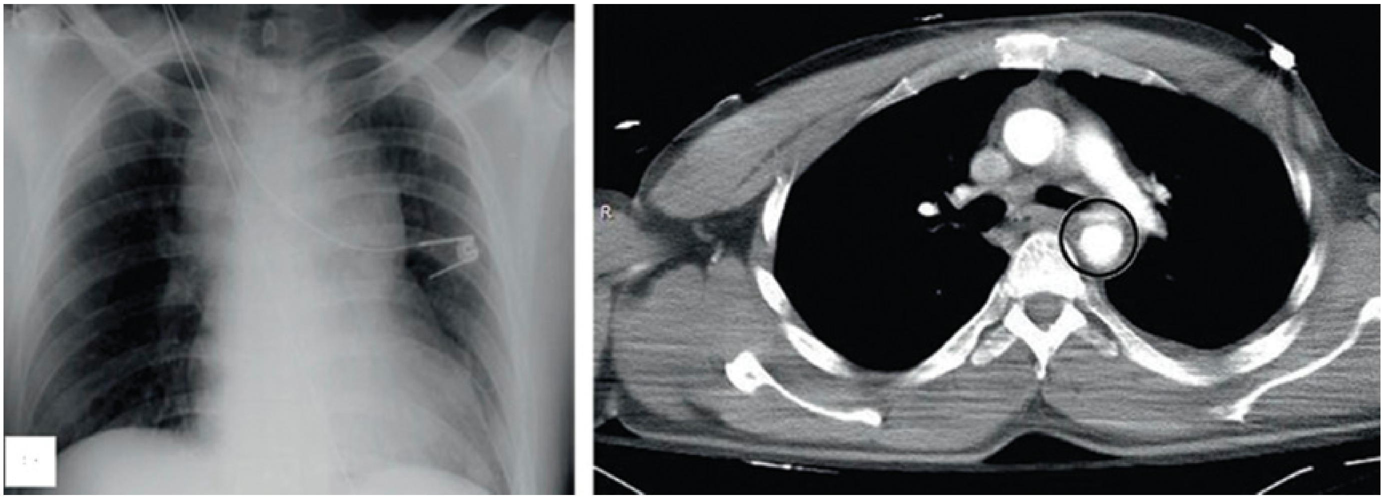


Figure 4.33 Blunt thoracic aortic injury. Chest X-ray shows a widened mediastinum CT image confirms thoracic aortic injury (circle)

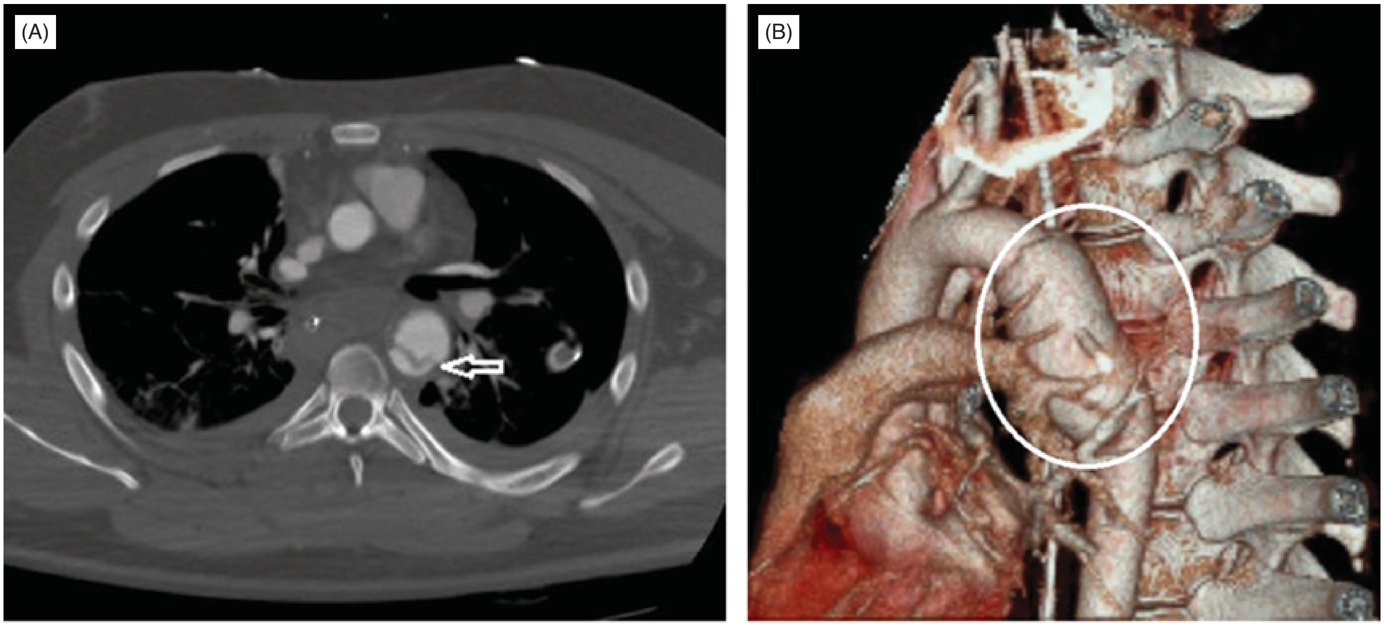


Figure 4.34 A,B Blunt thoracic aortic injury. CT angiography with 3-D reconstruction shows a contained aortic rupture.

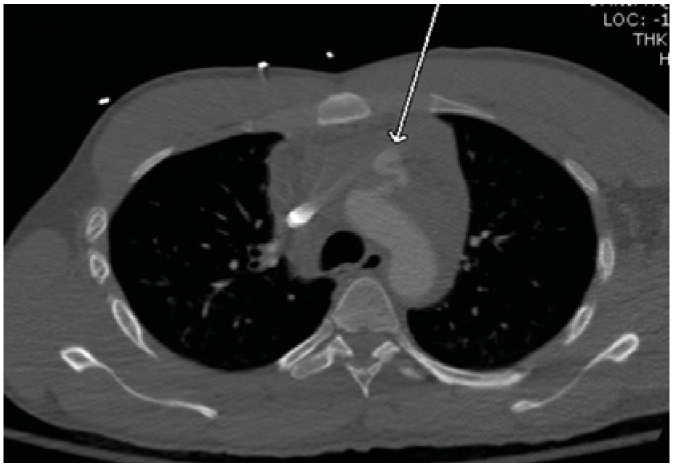


Figure 4.35 CT image of a blunt thoracic aortic injury with uncontrolled leak (arrow). This patient needs an emergency operation.

injuries distal to the left subclavian artery (Figure 4.36 A,B). The endovascular repair is associated with significantly lower in-hospital mortality, complications, and blood transfusions compared to the traditional open operative repair. While

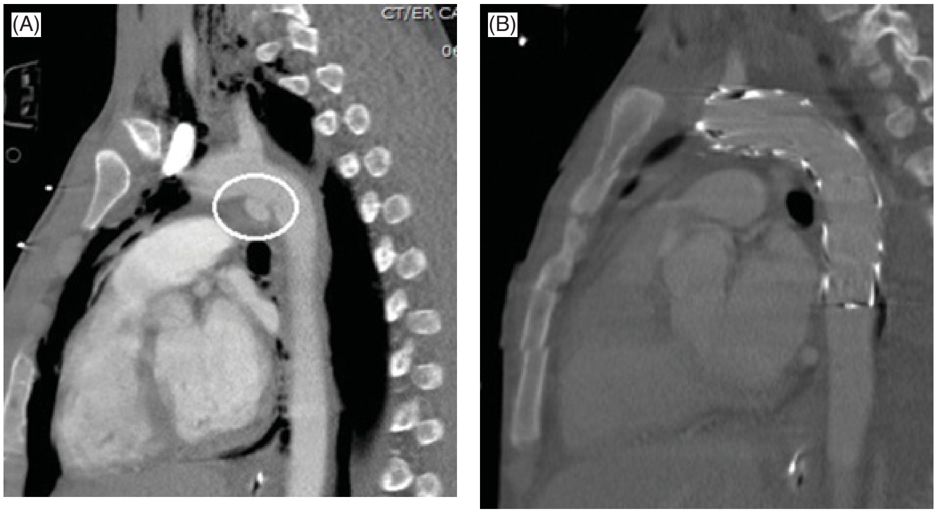


Figure 4.36 A,B CT angiogram showing an aortic pseudoaneurysm (A). The aneurysm was managed with an endovascular stent-graft deployment (B).

preparing for definitive aortic repair, judicious fluid management and the addition of beta-blockers or nitroprusside may be needed to maintain a lower systolic blood pressure, in order to control wall stress on the aorta and minimize the risk of free rupture. Other major associated injuries, such as intra-abdominal trauma or head injury, should be addressed before the definitive management of the aortic injury. The aortic repair in contained ruptures can be safely delayed for a few days, as long as the blood pressure is controlled. Multi-trauma elderly patients with minor aortic injuries can safely be managed nonoperatively.

Penetrating Thoracic Outlet Injuries

The most important structures of the thoracic outlet are the aortic arch with its major branches (innominate artery, origin of left carotid artery, and left subclavian artery), the superior vena cava, the innominate veins, and the subclavian veins.

Hemodynamically stable patients with penetrating injuries in this anatomical area should be investigated for vascular injuries. CTA is an excellent investigation for suspected thoracic outlet vascular injuries. Catheter-based angiography should be reserved for cases with shotgun injuries or when the CTA evaluation is not definitive or endovascular stenting is a possibility. Injuries to the branches of the aortic arch require surgical repair, though angiographically placed endovascular stents can be used in selected cases with false aneurysms or arteriovenous fistulas (Figure 4.37, Figure 4.38).

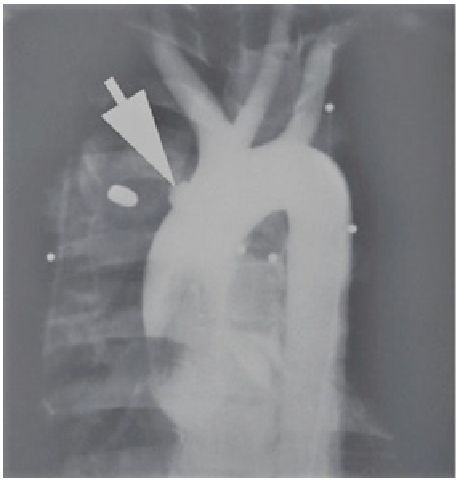


Figure 4.37 Patient with a gunshot wound to the thoracic inlet, hemodynamically stable. Angiography showing a small aneurysm of the ascending thoracic aorta (arrow)

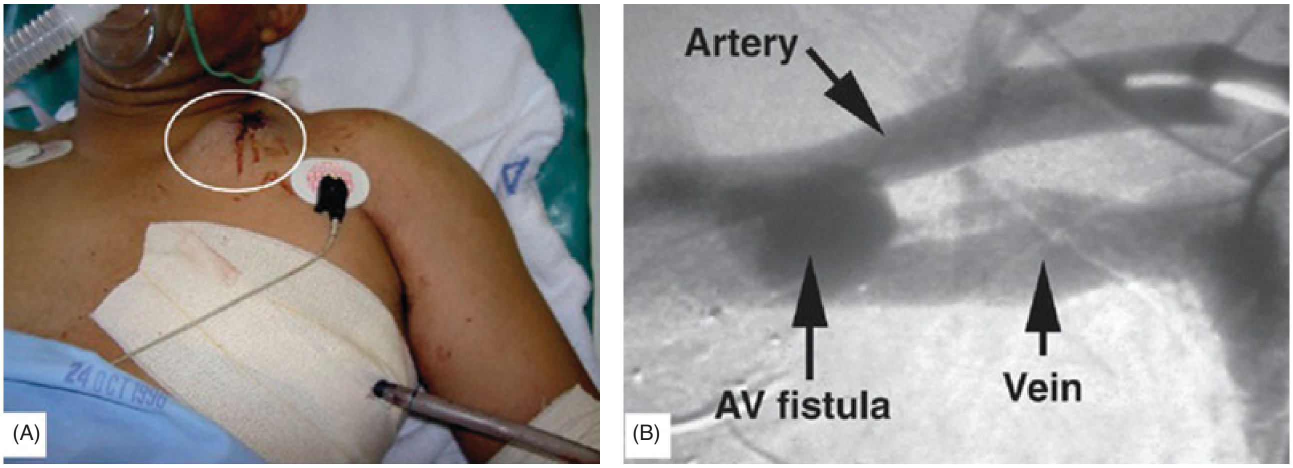


Figure 4.38 A,B Patient with a stab wound to the thoracic inlet, presenting with a large pulsating hematoma, diminished radial pulse, and a bruit on auscultation (A). Arteriography showing an arteriovenous fistula between the subclavian artery and vein (B). The injury was successfully managed with angiographic stenting.

Transmediastinal Gunshot Wounds

Transmediastinal gunshot wounds are associated with a high incidence of major injuries to the mediastinal structures. Hemodynamically unstable patients should have an emergency operation. About 70% of hemodynamically stable patients do not have significant injuries requiring surgical repair. These patients need evaluation of the mediastinal structures (heart, aorta, esophagus, tracheobronchial tree). CTA, as a screening investigation, should be performed in all hemodynamically stable patients. If the bullet tract is near the trachea, bronchi, or esophagus, directed studies, including endoscopy and esophagography, should be performed (Figure 4.39 A,B, Figure 4.40 A–C).

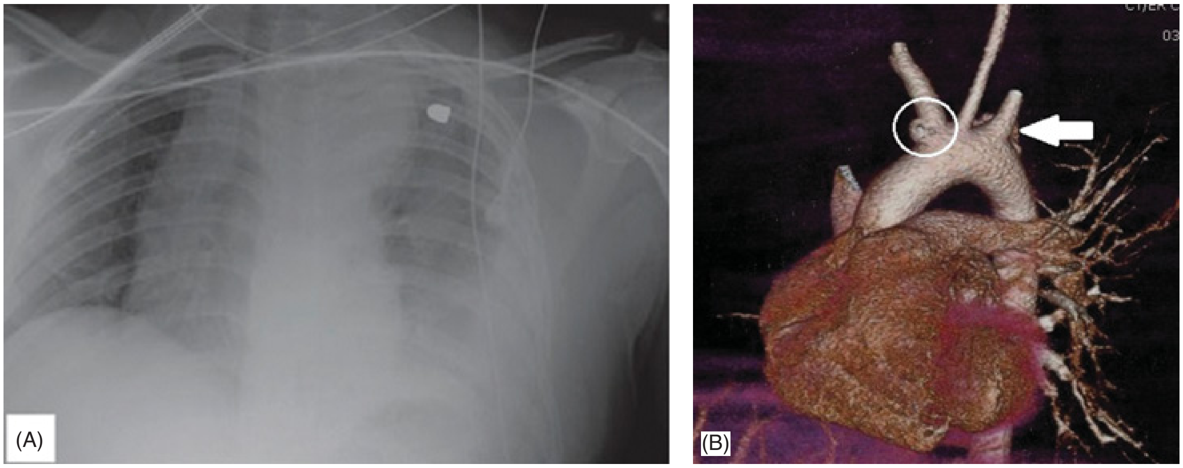


Figure 4.39 A,B Transmediastinal gunshot wound, admitted with transient hypotension. Chest X-ray shows a very widened mediastinum, a finding that is highly suspicious for a vascular injury (A). CTA showing a false aneurysm at the origin of the innominate artery (circle) and a second leaking false aneurysm in the posterior wall of the aorta, at the origin of the left subclavian artery (arrow; B).

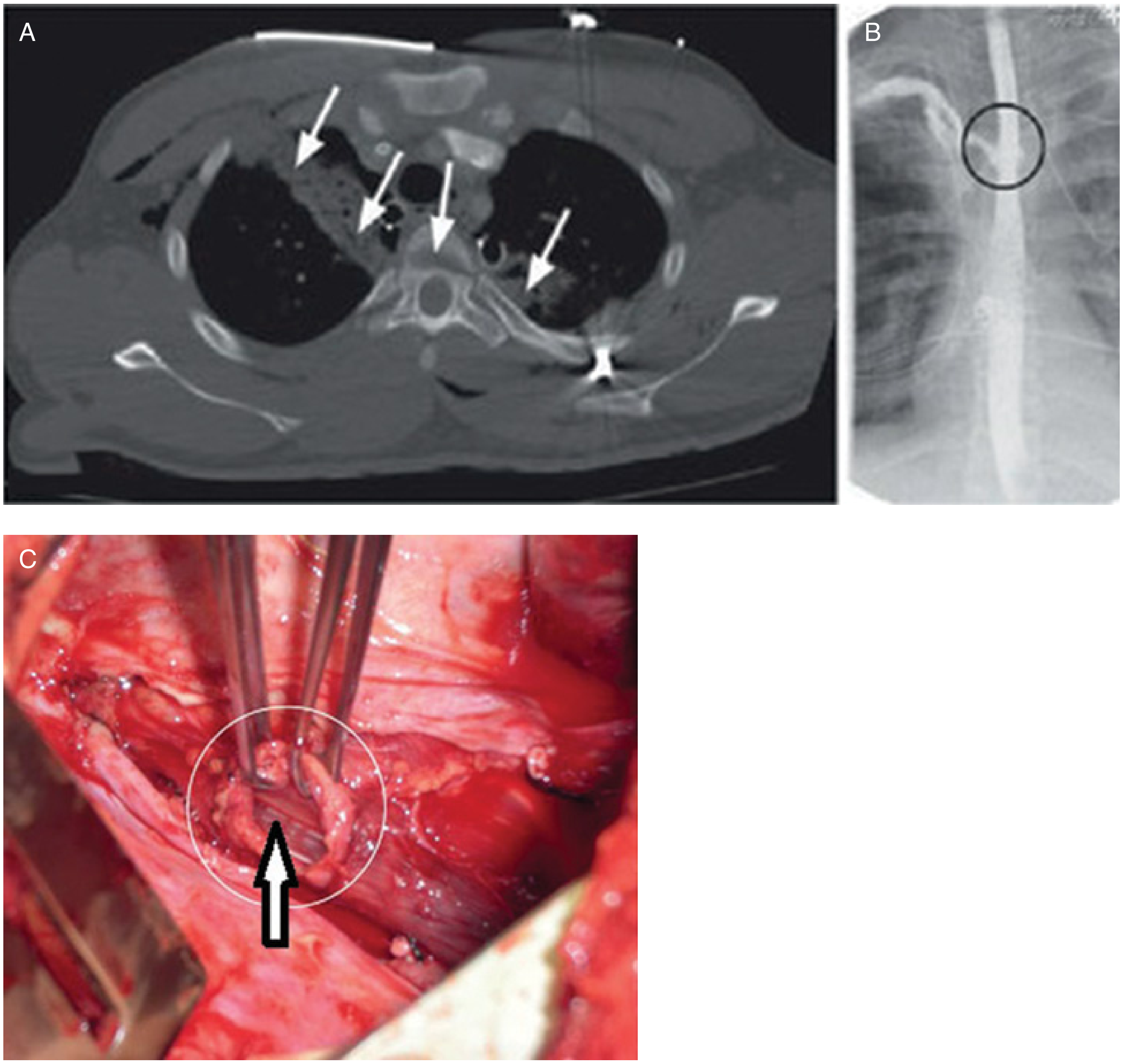


Figure 4.40 A–C Patient with transmediastinal gunshot wound, hemodynamically stable on admission. CT scan showing a bullet tract very close to the esophagus (arrows; A). This is a strong indication for further esophageal evaluation. Esophagogram shows a leak (circle) from the upper thoracic esophagus (B). Intraoperative photograph of the esophageal injury with a visible nasogastric tube (circle; C)

Diaphragmatic Injuries

Penetrating Diaphragmatic Injuries

About 60% of all gunshot wounds and 30% of all stab wounds to the left thoracoabdominal area (the area between the nipple and costal margin anteriorly and the tip of the scapula and lower ribs posteriorly) are associated with diaphragmatic injuries. About 10% of gunshot wounds and 30% of stab wounds to this area with no abdominal symptoms have diaphragmatic injuries. Unrecognized diaphragmatic injuries may result in diaphragmatic hernias, sometimes many months or years after the injury. To prevent this complication, early diagnosis and repair of all injuries to the left diaphragm are essential. Right diaphragmatic injuries, with the exception of anterior injuries, rarely result in hernias because of the protective presence of the liver.

The diagnosis of penetrating diaphragmatic injury should be suspected from the presence of a wound over the thoracoabdominal area. The chest X-ray is normal in the majority of patients with uncomplicated diaphragmatic perforations. An elevated hemidiaphragm is suspicious but not diagnostic of diaphragmatic injury. Conditions that may be associated with an elevated diaphragm include atelectasis, hepatic or splenic hematoma, gastric dilatation, fractures of the lower ribs, and phrenic nerve injury. CT scan and MRI are often not diagnostic in small, uncomplicated diaphragmatic injuries. For this reason, routine laparoscopy for all asymptomatic patients with suspicious penetrating wounds in the left thoracoabdominal or anterior right thoracoabdominal regions is recommended (Figure 4.41 A–E).

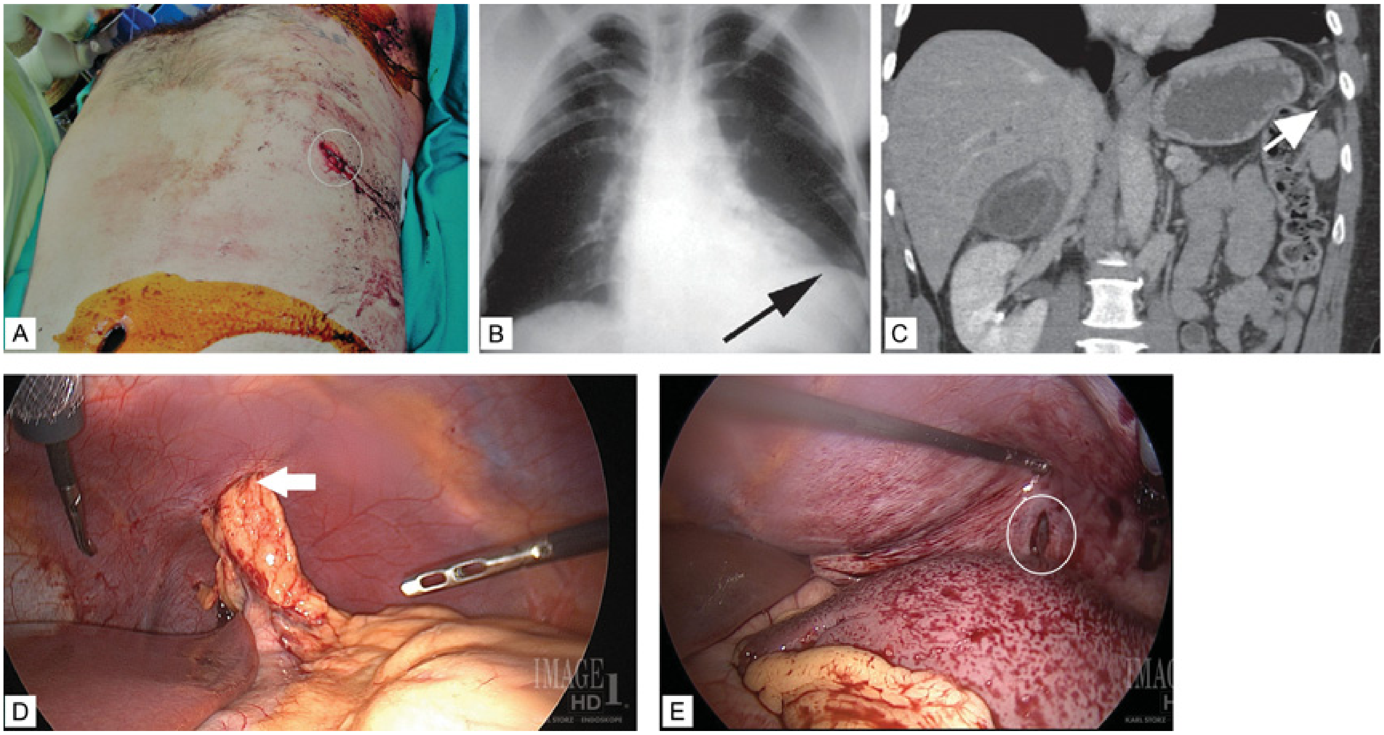


Figure 4.41 A–E Penetrating diaphragmatic injuries. Photograph of stab wound to the left thoracoabdominal area (circle; A). Penetrating trauma in this area is highly suspicious for diaphragmatic injury. Chest X-ray shows an elevated left diaphragm (arrow), which is suspicious for diaphragmatic injury (B). CT scan shows a left diaphragm injury (arrow; C). Laparoscopy showing a diaphragmatic injury with omentum herniating int the chest (arrow; D). Diaphragmatic perforation after reduction of the herniating omentum (circle; E).

Blunt Diaphragmatic Injuries

Rupture of the diaphragm is found in about 7% of all laparotomies for blunt trauma. The left diaphragm is involved in about 70% of the cases and the right diaphragm in about 30%. In about 3% of cases, both diaphragms are ruptured. The tear is about 7–10 cm long, as compared with 2–3 cm in penetrating trauma. Blunt abdominal trauma with a sudden increase of the intra-abdominal pressure (usually in belted car occupants) is the most common mechanism of diaphragmatic rupture, though fractured ribs may also cause tears. Deceleration injuries may cause detachment of the diaphragm from the ribs.

The chest X-ray, CT scan, or MRI are usually more diagnostic than in penetrating trauma because of the larger size of the diaphragmatic tear in blunt trauma. In most patients, there are major associated intra-abdominal injuries, and the diagnosis of diaphragmatic injury is made intraoperatively. However, in some cases, there is no associated abdominal trauma, and in the absence of herniation, the diagnosis of diaphragmatic tear may be missed. Laparoscopy in suspected cases remains the most reliable investigation (Figure 4.42 A,B).

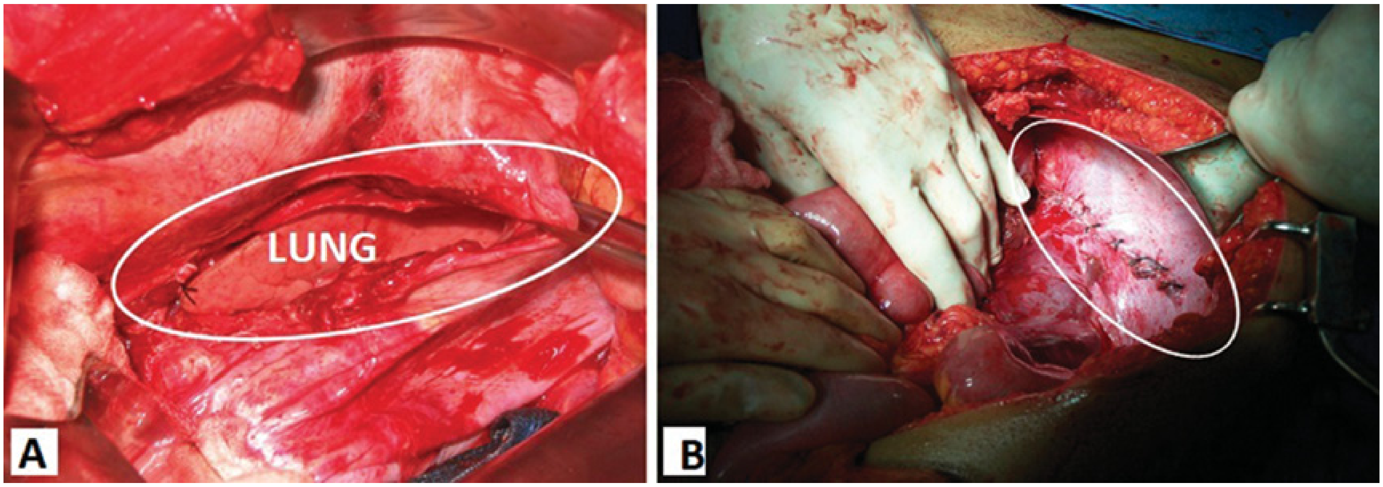


Figure 4.42 A,B A,B Blunt diaphragmatic rupture: high-speed motor vehicle collision with left diaphragmatic rupture. Note the lung through the tear (A). Post-repair of the injury (B).

Traumatic Diaphragmatic Hernias

Traumatic diaphragmatic hernias may appear within minutes, hours, days, weeks, or many years after injury to the diaphragm. In the vast majority of cases, the hernia is found in the left diaphragm, although right diaphragmatic hernias may occur as well. The most commonly herniating viscera are the omentum, stomach, and colon, followed by the small bowel, liver, and spleen, with the tail of pancreas.

Many hernias remain asymptomatic and are discovered during routine chest X-ray. Other patients present with signs of gastrointestinal obstruction, respiratory distress, and sepsis due to a gangrenous viscus. The diagnosis is suspected from the chest X-ray and history of previous trauma and confirmed by CT scan, MRI, or contrast studies. A nasogastric tube may be seen curling into the left chest on X-ray and is pathognomonic of gastric herniation. A radiologic "collar sign" with herniating liver is a notable sign of right diaphragmatic rupture. The radiologic appearance of a diaphragmatic hernia on chest X-ray may be confused with many other pathologies, such as lung laceration, bronchopneumonia, residual hemothorax, phrenic nerve injury, intrapulmonary abscess, and diaphragmatic eventration. The history of trauma and high index of suspicion remain the cornerstone of early diagnosis. Delayed diagnosis of a complicated diaphragmatic hernia (obstruction, ischemia or necrosis, or cardiorespiratory complications due to compression) is associated with high mortality. All diaphragmatic hernias require surgical repair (Figure 4.43 A,B, Figure 4.44 A,B, Figure 4.45 A–E, Figure 4.46 A,B).

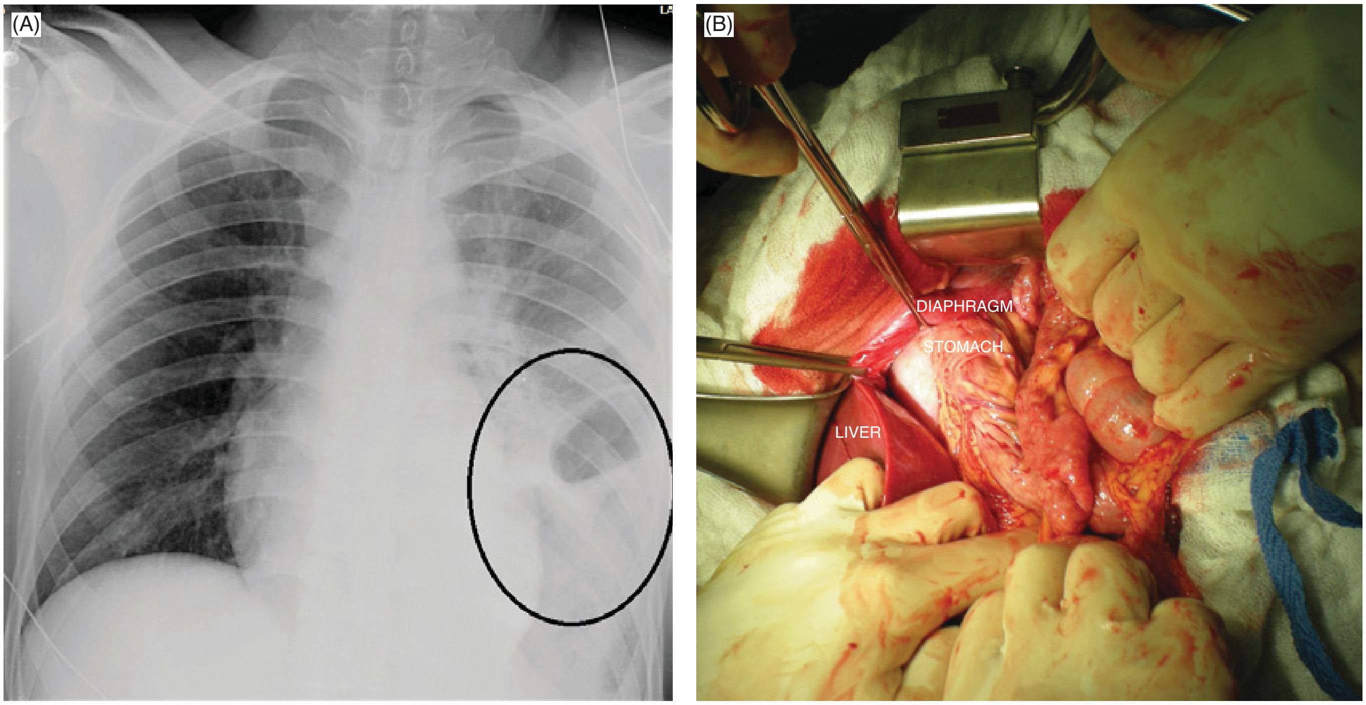


Figure 4.43 A,B Radiographic appearance of traumatic diaphragmatic hernias. Chest X-ray with a suspicious shadow (circle) at the base of the left hemithorax following a stab wound many months earlier (A). Further investigations showed gastric herniation into the chest. Chest X-ray shows the nasogastric tube curling into the left chest (arrow), pathognomonic of gastric herniation (B).

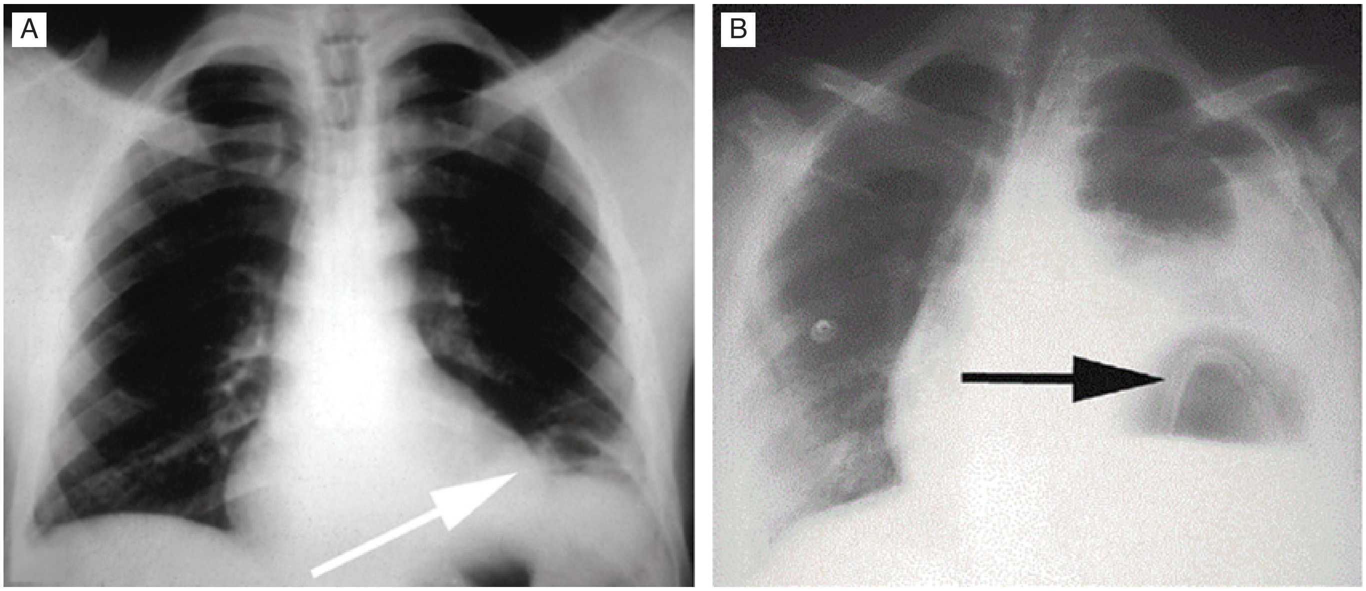


Figure 4.44 A,B Patient with a previous stab wound to the left thoracoabdominal area, many months previously, presents with abdominal pain and vomiting. Chest X-ray showing an abnormal shadow in the left lower chest (arrow), suspicious for diaphragmatic hernia (A). Patient with a history of a stab wound to the left thoracoabdominal area many years previously, presenting with upper abdominal pain and vomiting. Chest X-ray showing the nasogastric tube in the chest (arrow), diagnostic of diaphragmatic hernia with gastric herniation (B).

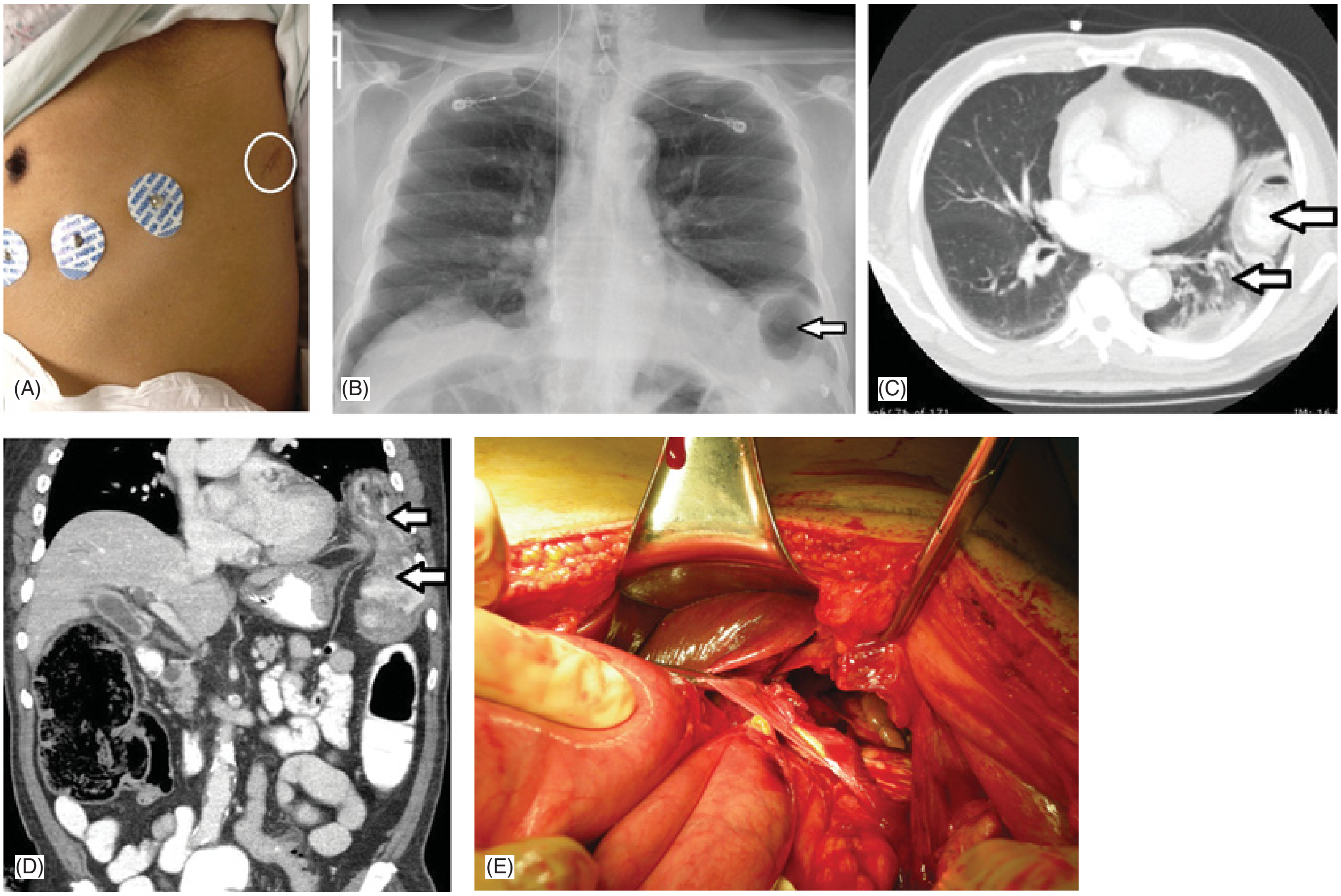


Figure 4.45 A–E Patient with a history of a knife wound many years previously, presents with abdominal pain, vomiting, and signs of bowel obstruction. On examination, there is a small wound scar in the left thoracoabdominal area (A). On chest X-ray, there is an abnormal left lower chest shadow (circle), suspicious of left diaphragmatic hernia (B). CT scan confirms a diaphragmatic hernia with herniating colon and omentum (arrows; D). Operative photo of the diaphragmatic defect after reduction of the colon and omentum (E).

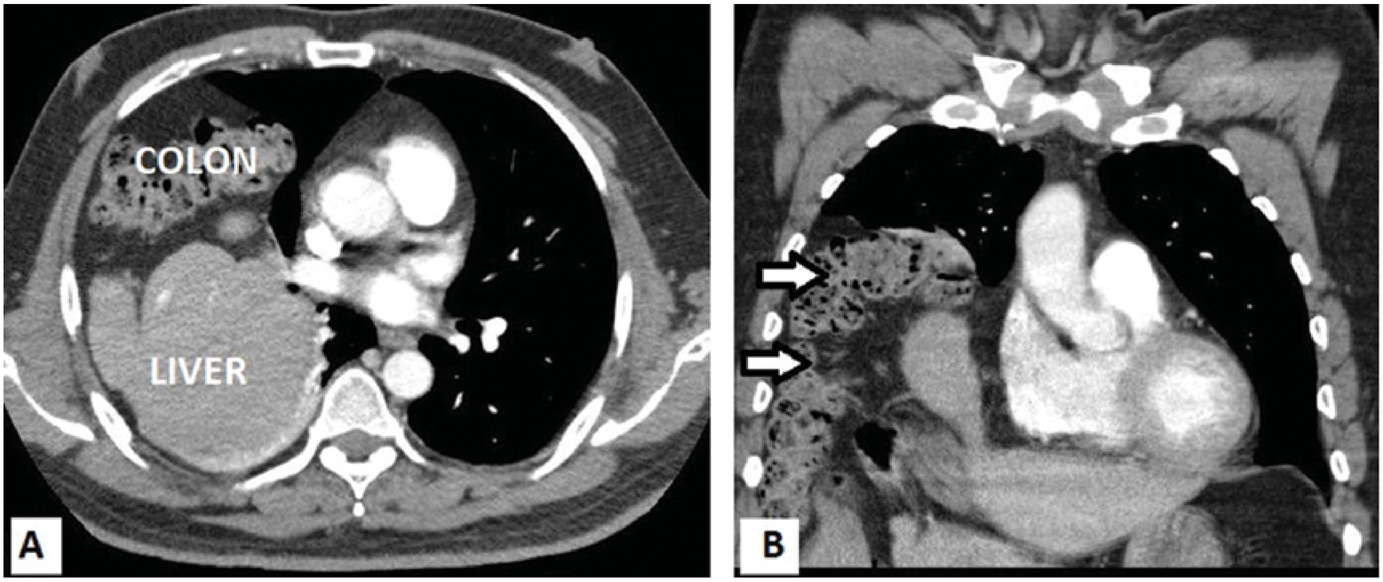


Figure 4.46 A,B Patient was involved in a motor vehicle collision a few weeks earlier. Presents with abdominal pain and signs of bowel obstruction. CT scan showing a large right diaphragmatic hernia with herniating liver and colon (arrows).

Esophageal Injuries

Esophageal injuries should be suspected in all penetrating mediastinal injuries, especially if the X-ray or CT scan shows mediastinal or subcutaneous emphysema in the neck, or the CT scan shows a missile tract near the esophagus. In suspected cases, esophagography and/or esophagoscopy should be performed. The combination of both investigations is highly sensitive in the identification of esophageal injuries. Early diagnosis and surgical repair are critical for good outcome. Delayed diagnosis is associated with a high incidence of sepsis and mortality (Figure 4.47 A,B, Figure 4.48 A–C).

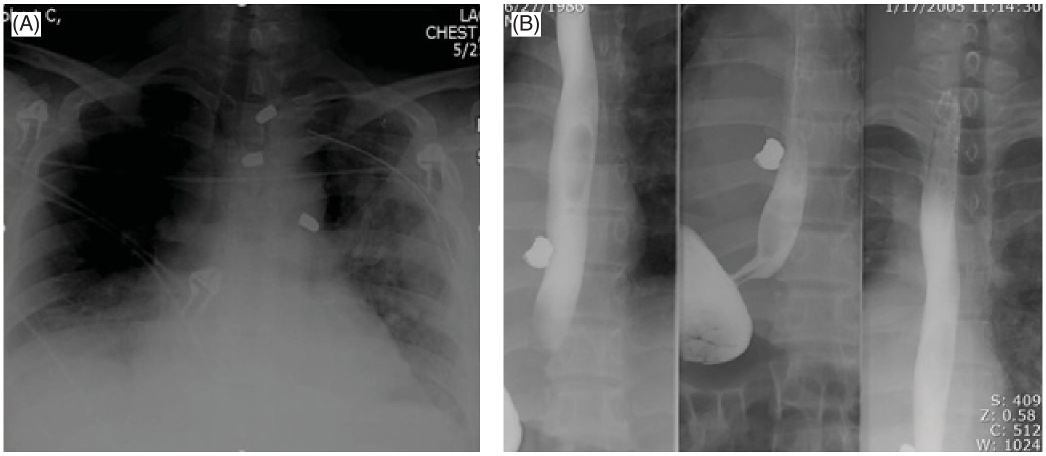


Figure 4.47 A,B Hemodynamically stable patients with mediastinal gunshot wounds should be evaluated with contrast CT scan, and if the missile tract is near the aerodigestive tract, endoscopy and esophagography should be performed. Patient with three bullets in the mediastinum (A). Normal esophagography (B).

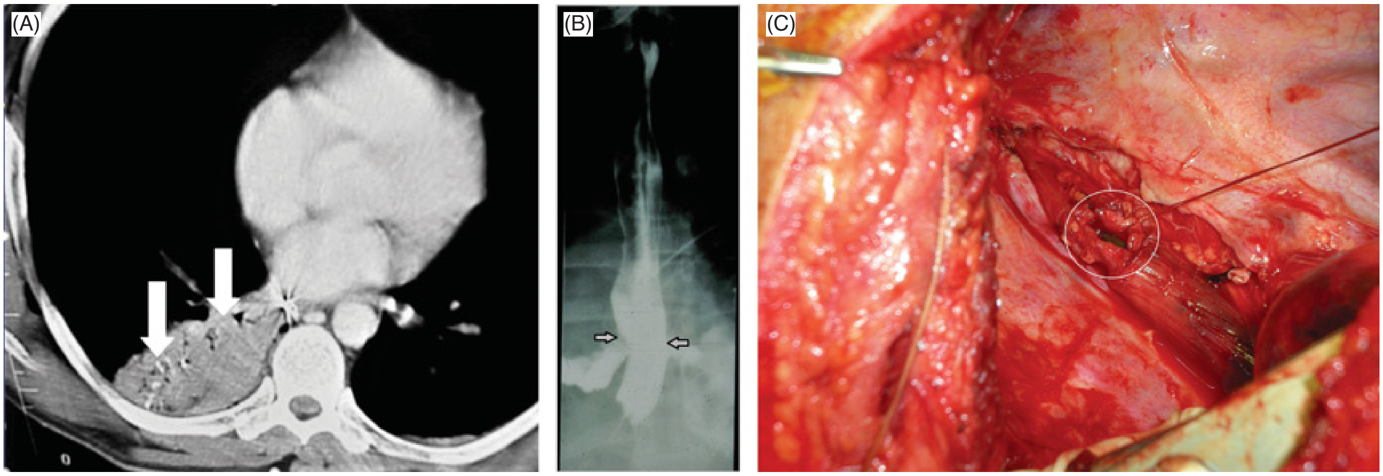


Figure 4.48 A–C Gunshot wound of the mediastinum. CT scan showing a missile tract (arrows) near the esophagus (A). Esophagography showing an esophageal injury (arrows; B). Photograph showing the esophageal perforation (C).

Thoracic Duct Injury

Rupture of the thoracic duct is usually due to penetrating trauma in the left supraclavicular region or the mediastinum and rarely due to blunt deceleration trauma. The diagnosis should be suspected in the presence of milky fluid in the pleural cavity. Sometimes in patients who have not received any oral feeding for a few days, the fluid may be clear or blood-stained. The diagnosis is confirmed by the presence of many lymphocytes and the high concentration of lipids in the fluid.

Most thoracic duct leaks heal nonoperatively with a low-fat oral diet or total parenteral nutrition. In patients with high output persisting for more than 2–3 weeks without any sign of improvement, a thoracotomy or thoracoscopy with thoracic duct ligation may be necessary (Figure 4.49 A–C).

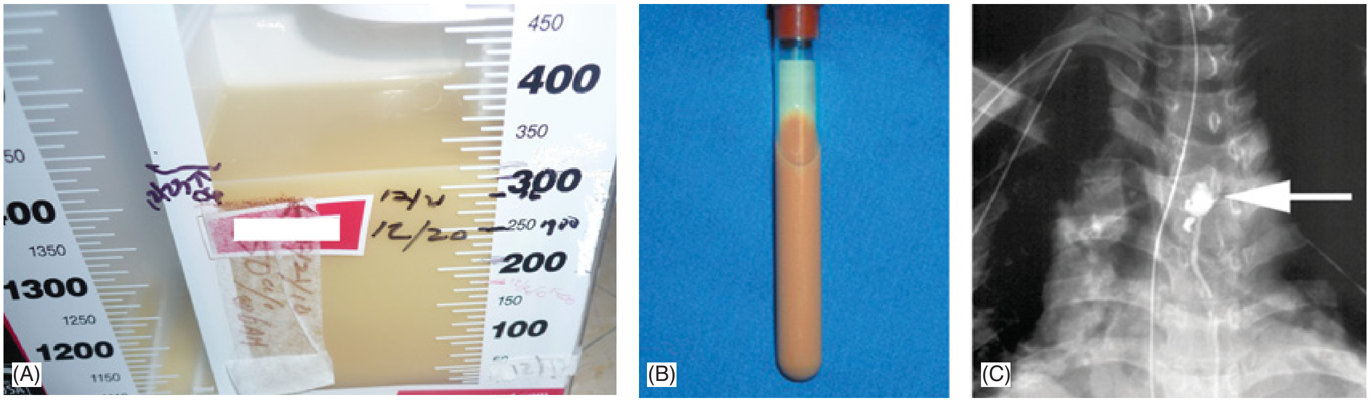


Figure 4.49 A–C Chylothorax. Chyle draining in the thoracostomy tube a few days after a mediastinal gunshot wound (A). Note the milky appearance of the fluid (B). Lymphangiogram shows a significant leak (arrow) from the thoracic duct (C).

Traumatic Asphyxia

Traumatic asphyxia is the result of severe crush injury to the chest. Because of the sudden increase of pressure in the venous and capillary systems, the victim develops extensive petechiae in the skin and conjunctivae. The petechiae appear in the face and upper part of the body (body regions drained by the superior vena cava). The lower part of the body is not affected because of the numerous venous valves, which prevent venous blood reflux. Similar microhemorrhages may develop in the brain and lungs, and the patient may present with central nervous or respiratory problems. The treatment is symptomatic (Figure 4.50 A–D).

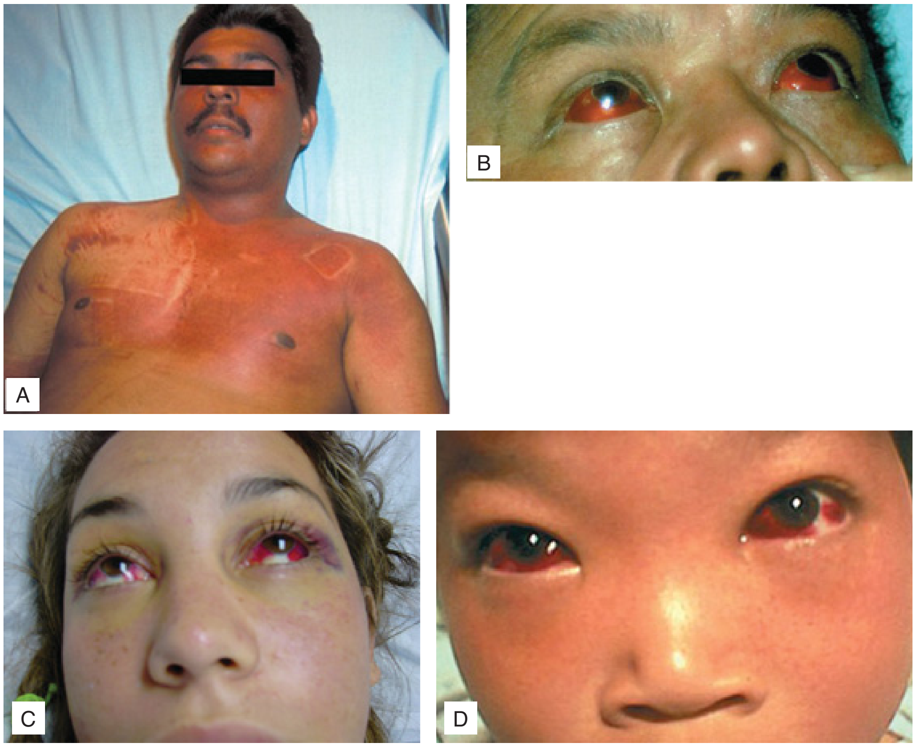


Figure 4.50 A–D Traumatic asphyxia. Photograph of a patient with crush trauma to the chest and traumatic asphyxia. Note the extensive petechiae on the face and chest (A). Note the conjunctival hemorrhages (B). Traumatic asphyxia with petechiae on the face and conjunctival hemorrhages, in a patient with thoracoabdominal crush trauma (C). Traumatic asphyxia with petechiae on the face and conjunctival hemorrhages in a child with chest crush trauma (D).

Impaled Thoracic Foreign Bodies

Impaled thoracic foreign bodies should not be removed on the scene of injury. Impaled foreign bodies should be taped to the torso during the transportation and removed in the operating room if the foreign body appears to be in proximity of intrathoracic vessels, pulmonary hilum, or mediastinal structures. Removal of the foreign body in an uncontrolled environment may result in uncontrolled hemorrhage and death. Hemodynamically unstable patients should undergo an emergency operation, after a FAST exam and chest X-ray. Hemodynamically stable patients should be evaluated by CTA before operation (Figure 4.51 A,B).

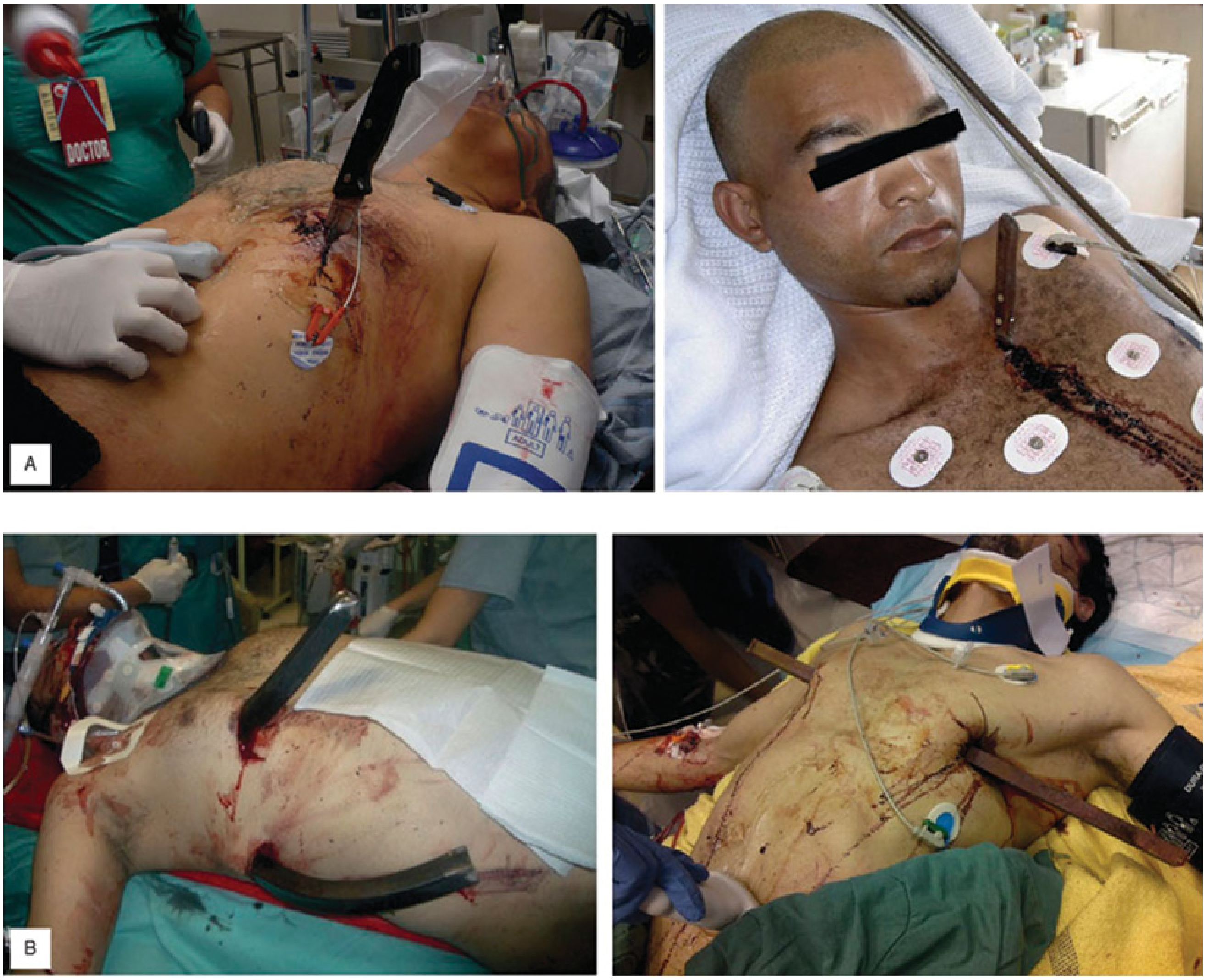


Figure 4.51 A,B Retained thoracic foreign bodies. Stab wounds to the chest with embedded knives (A). Photographs of patients sustaining penetrating injuries and impaled large rods. The impaled objects should be removed under the direct control of the surgeon, usually in the operating room (B).

Tips and Pitfalls

- Elderly patients with multiple rib fractures or lung contusions or patients with flail chest may seem stable on admission, but rapid respiratory deterioration is common. Consider admission to the intensive care unit for close monitoring and liberal early intubation.
- In suspected tension pneumothorax, chest needle decompression at the fourth or fifth intercostal space at the anterior axillary line is more successful than the previously suggested second intercostal space at the mid-clavicular line. In pediatric patients, the mid-clavicular line remains the preferred site of decompression.
- Restlessness in cardiac tamponade may be misinterpreted as alcohol or drug intoxication.
- FAST exam may be false negative for pericardial tamponade when pericardial perforation allows hemopericardium to decompress to chest cavity.
- A widened mediastinum on chest X-ray following a traffic collision or a fall from a height may be due to rupture of the

thoracic aorta or cardiac tamponade or due to fractures of the thoracic spine or the sternum.

- Traumatic rupture of the thoracic aorta may not be associated with an abnormal mediastinum on chest X-ray. In high-speed deceleration trauma, all patients should be evaluated by CTA of the chest to rule out aortic injury.
- In asymptomatic left thoracoabdominal penetrating injuries, diaphragmatic injury is common, and radiographic imaging is commonly not reliable. These patients should be evaluated with laparoscopy.

Chapter

5

Abdominal Trauma

Demetrios Demetriades and Kenji Inaba

Blunt Abdominal Trauma

Introduction

Traffic collisions, followed by falls, are by far the most common cause of severe blunt abdominal trauma. Solid organs, usually the spleen and liver, are the most commonly injured organs. Hollow viscus perforations are fairly uncommon (about 3% of blunt abdominal trauma), and they are often associated with seat-belts or high-speed deceleration injuries.

There are five main mechanisms of injury with blunt trauma:

1. Direct crushing of organs between the anterior and posterior abdominal walls
2. Avulsion injuries from deceleration forces, as in high-speed collisions or falls from a height
3. Transient formation of a closed bowel loop with high intraluminal pressure and rupture of the hollow viscus.
4. Lacerations by bony fragments (e.g., pelvis, lower ribs).
5. Sudden and massive elevation of the intra-abdominal pressure (usually seat-belted individuals involved in high-speed collisions) may cause diaphragmatic or even cardiac rupture.

Clinical Examination

The clinical evaluation of blunt abdominal trauma is often complicated by associated abdominal wall trauma, fractures of the lower ribs or pelvis, head injuries with depressed level of consciousness, and spinal injuries. These conditions may make clinical examination difficult and unreliable, and significant hollow viscus injuries may be missed with potentially serious consequences.

Rigidity and severe or increasing abdominal tenderness are suggestive of developing peritonitis. These findings, however, may be less reliable in patients with abdominal wall bruising, or fractures of the lower ribs or pelvis. Pain referred to the left shoulder (Kehr's sign) is suggestive of splenic injury. Similarly, pain referred to the right shoulder is suggestive of hepatic injury. Often, these signs can be elicited by placing the patient in the Trendelenburg position. A "seat-belt sign" on the abdominal wall is associated with a high incidence (about 20%) of significant intra-abdominal injuries.

Investigations

1. FAST: FAST is the most valuable emergency department investigation in the evaluation of abdominal trauma. The FAST uses ultrasound to identify the presence or absence of free intraperitoneal fluid by evaluating the hepatorenal, splenorenal, and suprapubic spaces (see Chapter 25, Ultrasound in Trauma). It is quick, noninvasive, safe, portable, and fairly accurate. The FAST exam is unable to evaluate the retroperitoneum, is operator dependent, and, if positive, does not identify the source of fluid. FAST is most useful when positive. Small volume hemoperitoneum or clotted blood can result in a false negative FAST. The presence of free fluid on ultrasound in a hemodynamically unstable patient is an indication for urgent laparotomy. However, in hemodynamically stable patients, an abdominal CT scan may be the most appropriate next step.
2. Plain X-rays: A chest X-ray is part of the abdominal evaluation. Routine pelvis X-ray in an alert asymptomatic patient is not indicated if a CT scan is planned. However, a pelvic X-ray is indicated in unstable patients with a suspected fracture, in order to evaluate the type of fracture and to determine the potential need and safety of a pelvic binder.
3. CT scan: Contrast CT scan has become the most important and useful investigation in the evaluation of suspected blunt abdominal trauma. It is very sensitive in diagnosing solid organ injuries. In addition to the site and size of solid organ injury, it may give valuable information about the presence of active bleeding or false aneurysms. The role of CT scan in the diagnosis of hollow viscus perforation is rather limited, and up to 30–40% of injuries may be missed, especially if the CT scan is performed very soon after the injury. CT scan findings suggestive of bowel injury include pneumoperitoneum, thickened bowel wall, extravasation of oral contrast, fat stranding, and free intraperitoneal fluid in the absence of solid organ injury.
4. Diagnostic peritoneal lavage (DPL): DPL has largely been replaced by the FAST exam. Diagnostic peritoneal aspirate (DPA), however, has an important role in the evaluation of the abdomen in a hemodynamically unstable patient, if the ultrasound is

not definitive or available. The procedure can be performed with the open or percutaneous closed technique (see Chapter 22, Diagnostic Peritoneal Aspirate). The aspiration of gross blood during a DPA is an indication for laparotomy in the hemodynamically unstable patient.

5. Intravenous pyelogram (IVP): One-shot IVP in the emergency department has little or no role in the evaluation of abdominal trauma. Formal IVP has largely been replaced by contrast CT scan, though it may still have a role in suspected ureteric injuries.
6. Catheter angiography: This is an important therapeutic tool in selected cases of abdominal trauma, where CT scan findings are suggestive of bleeding from pelvic fractures or solid organ injuries, false aneurysms, or arteriovenous fistulas.
7. Magnetic resonance cholangiopancreatography (MRCP): This is a good investigation for the evaluation of the integrity of the pancreatic duct in pancreatic trauma.
8. Urinalysis: All patients should be evaluated for hematuria. Gross hematuria should be evaluated by means of contrast CT scan and cystogram. Asymptomatic microscopic hematuria does not need further evaluation.
9. Serum amylase and lipase: These levels may be useful laboratory tests for suspected pancreaticoduodenal trauma, although the sensitivity and specificity are fairly low. Normal levels do not reliably exclude pancreatic trauma, and they are elevated in only about 70% of cases with proven pancreatic trauma. Serum amylase will rise more rapidly after pancreatic trauma; however, it is less specific. Serum lipase levels may be in normal range soon after pancreatic trauma and may not show significant elevation until the following day. Serial measurements are more useful than the initial values.

General Management

The initial evaluation and management should follow standard ATLS protocols. A FAST exam is part of the standard evaluation of all patients with abdominal trauma. Hemodynamically unstable patients with a positive FAST should be taken to the operating room without delay. CT scan evaluation should be reserved only for the patient who is hemodynamically stable and whose diagnosis is uncertain.

In the multi-trauma patient, there is often combined abdominal and head trauma. The timing of evaluation and management of the injuries of these two anatomic areas is important and can have major effects on outcome. In the presence of hemodynamic instability, the abdomen should be evaluated by FAST, and in the setting of an equivocal FAST, a DPA is performed. If there is evidence of free intraperitoneal fluid, the patient should undergo laparotomy with a post-operative head CT scan. If there are localizing neurological signs, burr holes may be considered during laparotomy before CT evaluation. This approach should be considered very rarely because the burr holes are often placed on the wrong site and it is a time-consuming procedure. In the hemodynamically stable patient with peritonitis and abnormal GCS, a CT scan of the head should precede laparotomy, under close monitoring. It is rare that both a laparotomy and a craniotomy are required simultaneously. Bleeding control in the abdomen is always the first priority.

Many carefully selected patients with solid organ injury (liver, spleen, kidney) can safely be managed nonoperatively, provided they are hemodynamically stable and have no signs of peritonitis. Overall, approximately 70% of blunt liver injuries, approximately 80% of splenic injuries, and 90% of renal injuries can be managed nonoperatively. Angioembolization should be considered in patients with CT scan evidence of active bleeding or false aneurysms.

Tips and Pitfalls

- Delayed diagnosis of hollow viscus perforation in a clinically unevaluable patient (e.g., associated head injury, spinal cord injury, or intoxication) is a serious complication. The presence of a seat-belt sign should raise the index of suspicion for abdominal trauma. Certain CT scan findings, such as bowel edema, intraperitoneal gas, and free intraperitoneal fluid in the absence of a solid organ injury, are suspicious of hollow viscus perforation. Serial WBC and follow-up abdominal CT scan should be considered in suspicious cases.
- Pancreaticoduodenal injuries are notorious for their fairly silent clinical presentation. The initial CT scan may miss the injury, and the serum amylase or lipase may be normal. Close clinical monitoring, repeat CT scan, and serial enzyme determinations should be performed.
- The FAST exam is not always reliable, and no major decisions should be made exclusively based on the findings of the FAST exam. The hemodynamic condition of the patient should be taken into account when deciding management.

Mechanism of Injury

Intra-abdominal injuries may occur by crushing of an organ against the spine, pelvis, or ribs and the abdominal wall; after deceleration, such as high-speed collisions or falls from a height by sudden increase of the intraluminal pressure and bursting of a hollow viscus, commonly seen with seat-belt injuries (Figure 5.1 A–C, Figure 5.2 A–C, Figure 5.3).

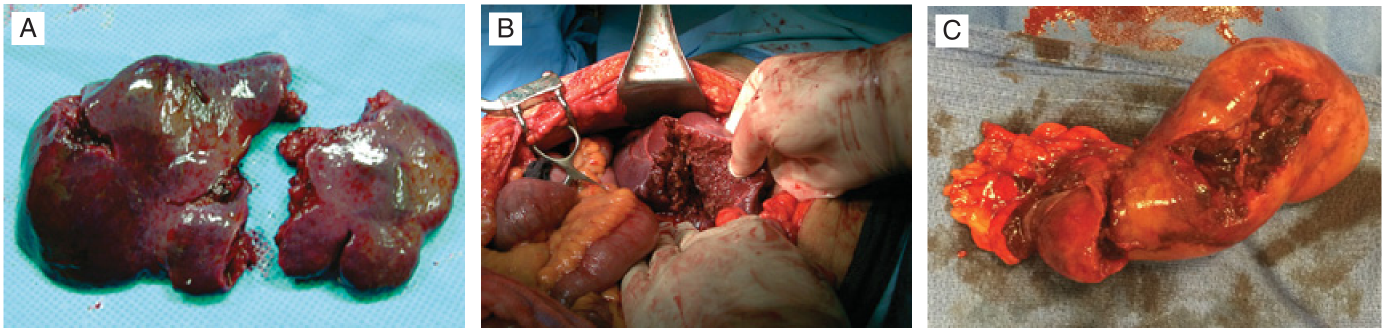


Figure 5.1 A–C Direct crushing injury to spleen following an auto versus pedestrian collision (A). Crushing injury to the liver following a motor vehicle collision (B). Crushing injury to the kidney following a fall from a height (C).

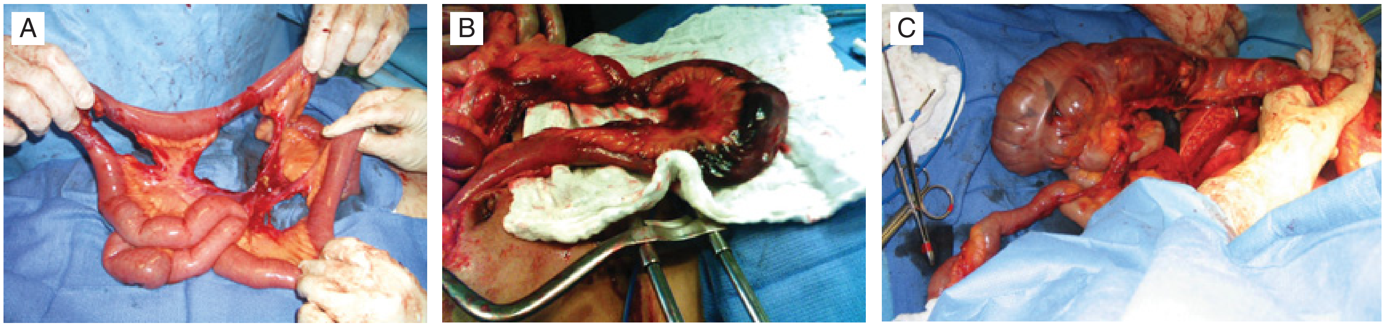


Figure 5.2 A–C Mesenteric "bucket handle" avulsion injury to small bowel from deceleration injury following a high-speed motor vehicle collision (A). Mesenteric "bucket handle" avulsion injury and necrosis of the small bowel, from deceleration injury following a high-speed motor vehicle collision (B). Deceleration injury with avulsion of the right colon and distal ileum, following a high-speed motor vehicle collision (C).

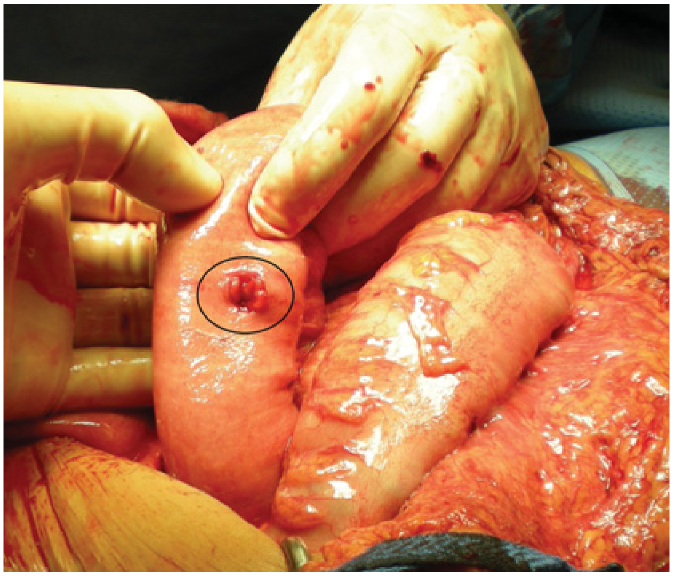


Figure 5.3 Small bowel rupture due to closed loop and increased intraluminal pressure. The rupture occurs at the antimesenteric border.

Seat-belts have significantly decreased mortality rates after motor vehicle collisions. Although the incidence of intra-abdominal injuries has not changed with the use of seat-belts, the nature of the injuries has changed: seat-belt wearers are more likely to suffer hollow viscus perforation.

The presence of seat-belt marks on the abdominal wall is an important physical finding because of the high incidence of associated intra-abdominal injuries. In patients wearing a seat-belt, approximately 20% with a seat-belt sign will have intra-abdominal injury versus only approximately 3% without a seat-belt sign (Figure 5.4 A,B).

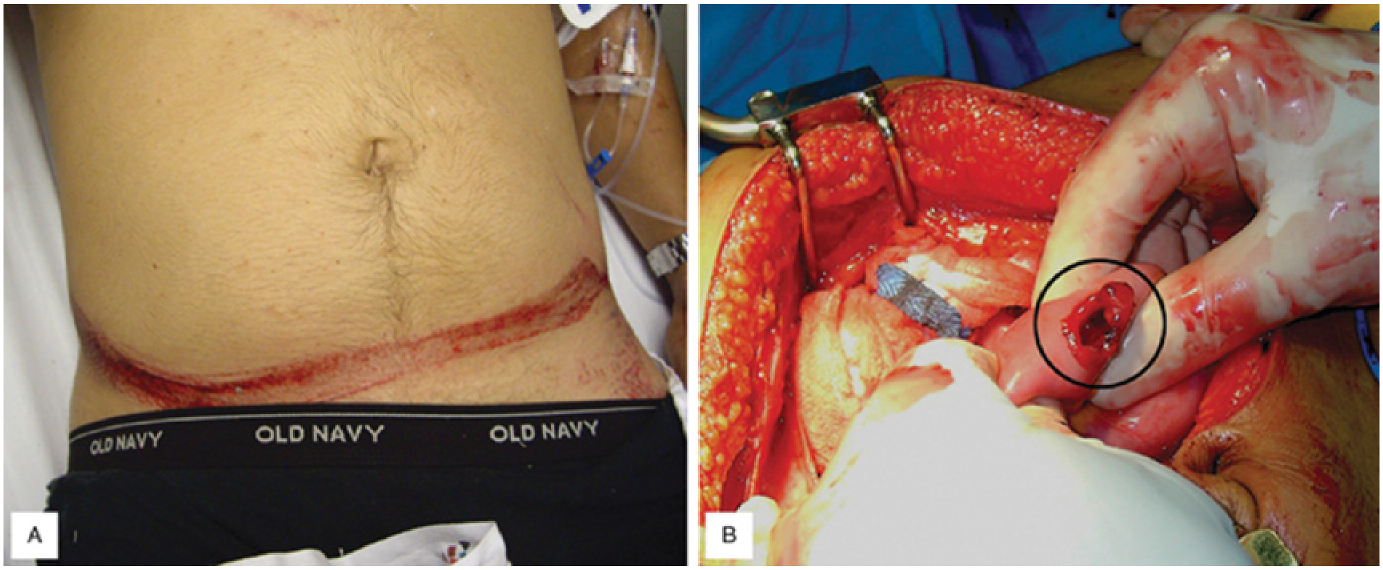


Figure 5.4 A,B Abdominal seat-belt mark in a motor vehicle collision victim. The presence of this sign is a marker associated with a high incidence of intraabdominal injury (A). Intraoperative photograph of the same patient showing perforation of the small bowel (B).

Diagnosis of Hemoperitoneum

Hemoperitoneum by itself usually does not result in peritoneal signs. Thus the clinical diagnosis, especially in the presence of multi-trauma, can be difficult. FAST exam, performed in the emergency department is a fast, usually reliable, and noninvasive method of detecting intraperitoneal bleeding. DPA has a role in the evaluation of an unstable patient when the FAST exam is not diagnostic or not available. CT scan evaluation should be considered in hemodynamically stable patients. Under these circumstances, CT scan is the most valuable investigation (Figure 5.5).

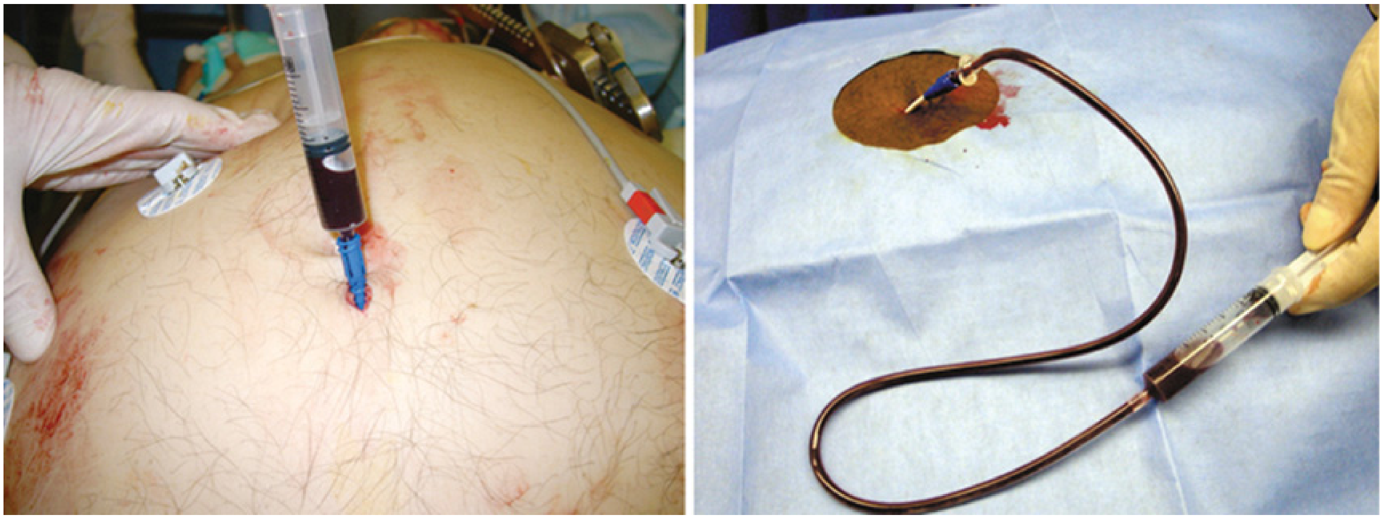


Figure 5.5 Positive diagnostic aspirate (DPA).

Splenic Injuries

The clinical presentation of splenic rupture may vary from mild left upper quadrant pain to severe hypovolemic shock. The diagnosis may be suspected from the clinical examination (pain in left upper abdomen often radiating to the left shoulder, signs of hypovolemia) or FAST exam showing free intraperitoneal fluid and confirmed by CT scan (Figure 5.6 A, B, Figure 5.7, Figure 5.8 A, B, Figure 5.9 A, B).

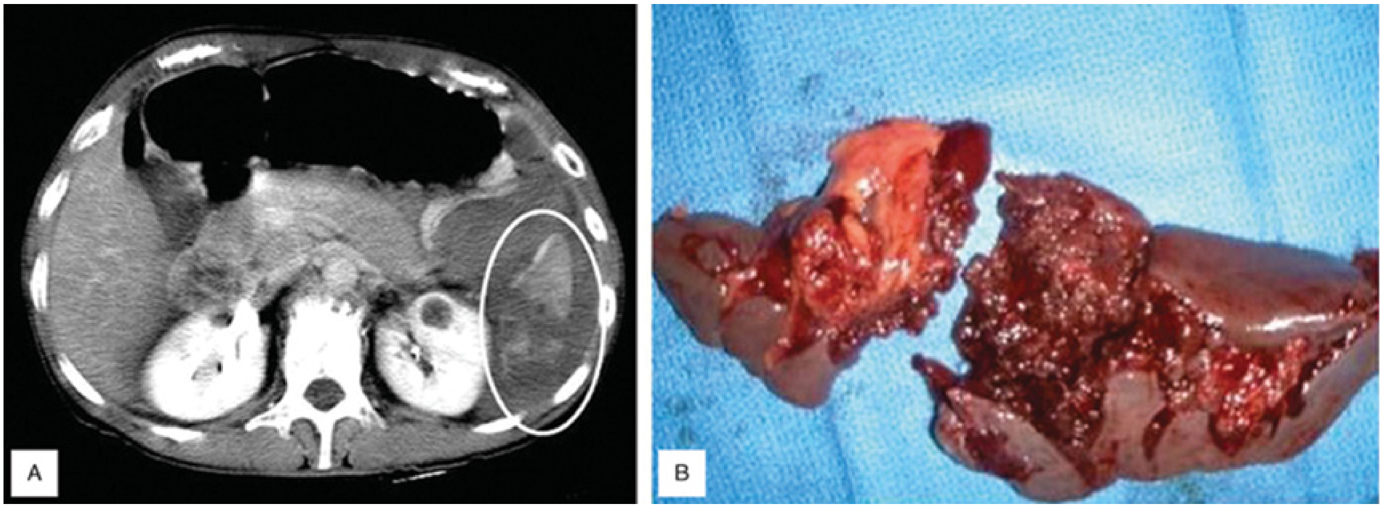


Figure 5.6 A,B Abdominal CT scan with a grade IV spleen injury (A). Surgical specimen of the removed ruptured spleen (B).

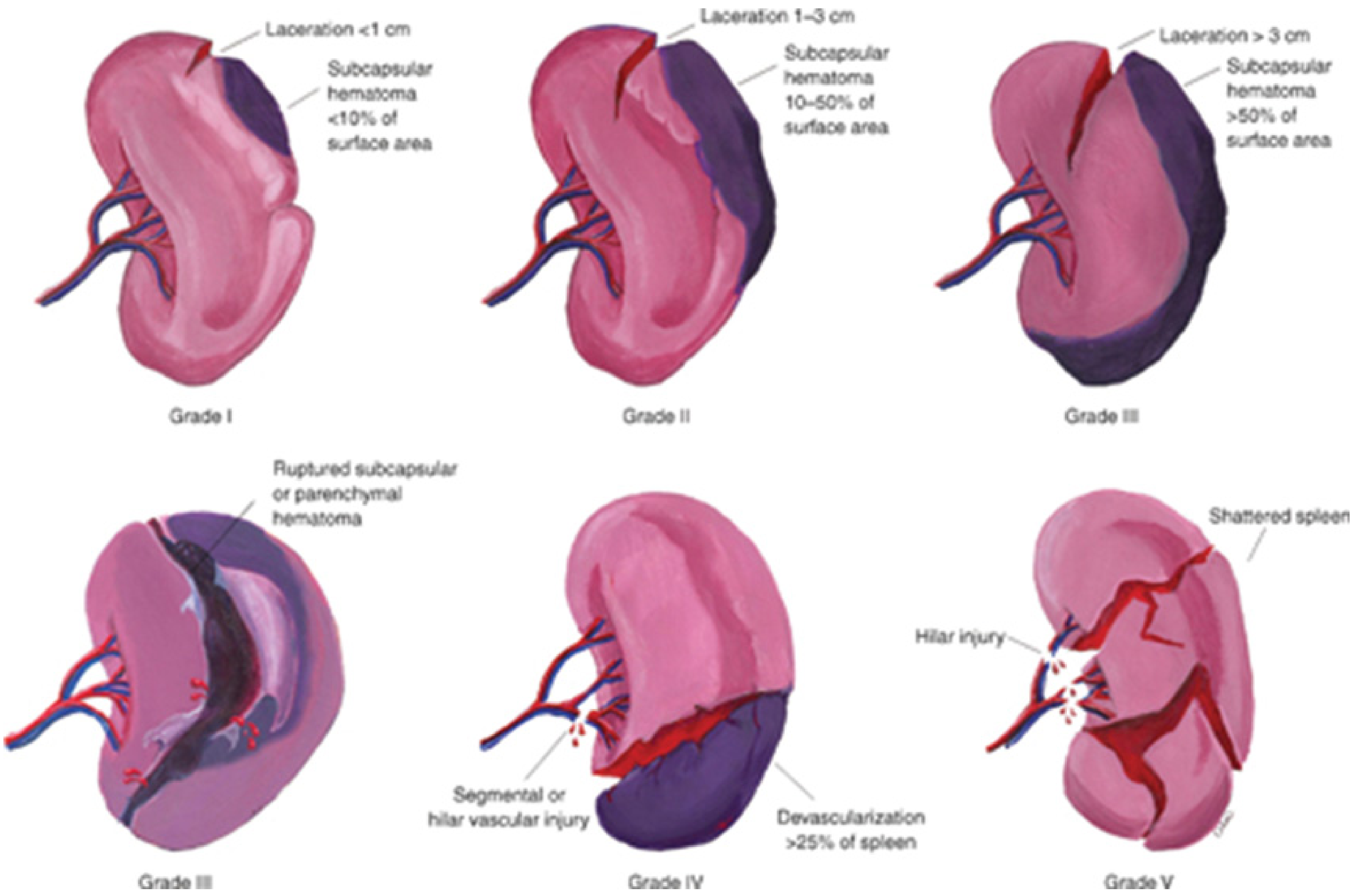

Laceration <1 cm
Subcapsular hematoma <10% of surface area
Grade I
Laceration 1–3 cm
Subcapsular hematoma 10–50% of surface area
Grade II
Laceration > 3 cm
Subcapsular hematoma >50% of surface area
Grade III
Ruptured subcapsular or parenchymal hematoma
Grade III
Segmental or hilar vascular injury
Devascularization >25% of spleen
Grade IV
Shattered spleen
Hilar injury
Grade V

Figure 5.7 Grades of splenic injuries, according to the American Association for the Surgery of Trauma classification. Most grade I–III injuries can safely be managed nonoperatively. The majority of grade IV or V injuries require operative management.

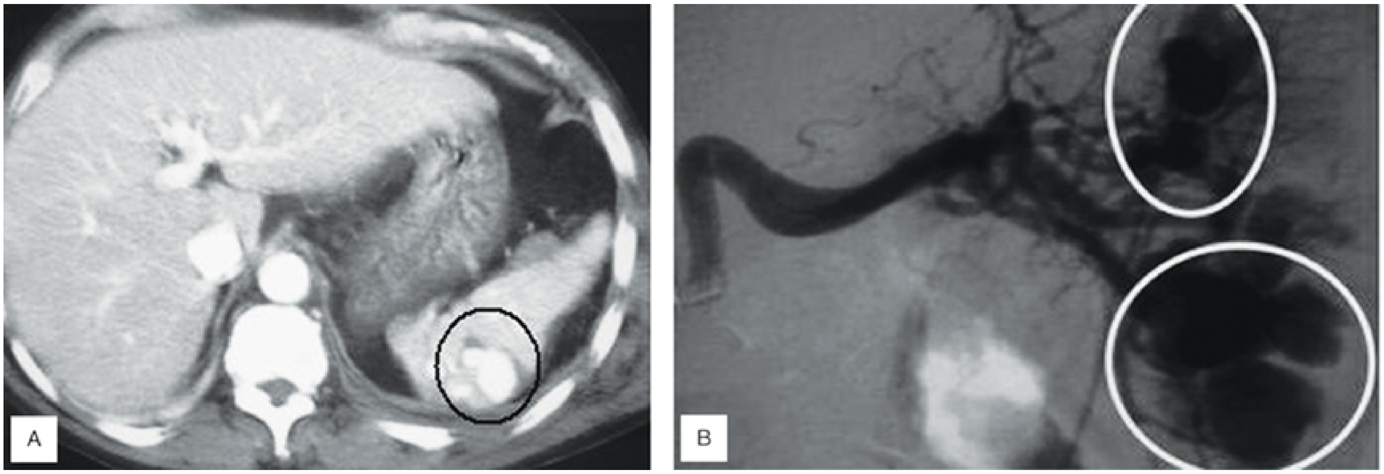


Figure 5.8 A,B CT scan showing a large intrasplenic aneurysm (A). Angiography showing multiple intrasplenic pseudoaneurysms (B). These injuries can be managed with angioembolization.

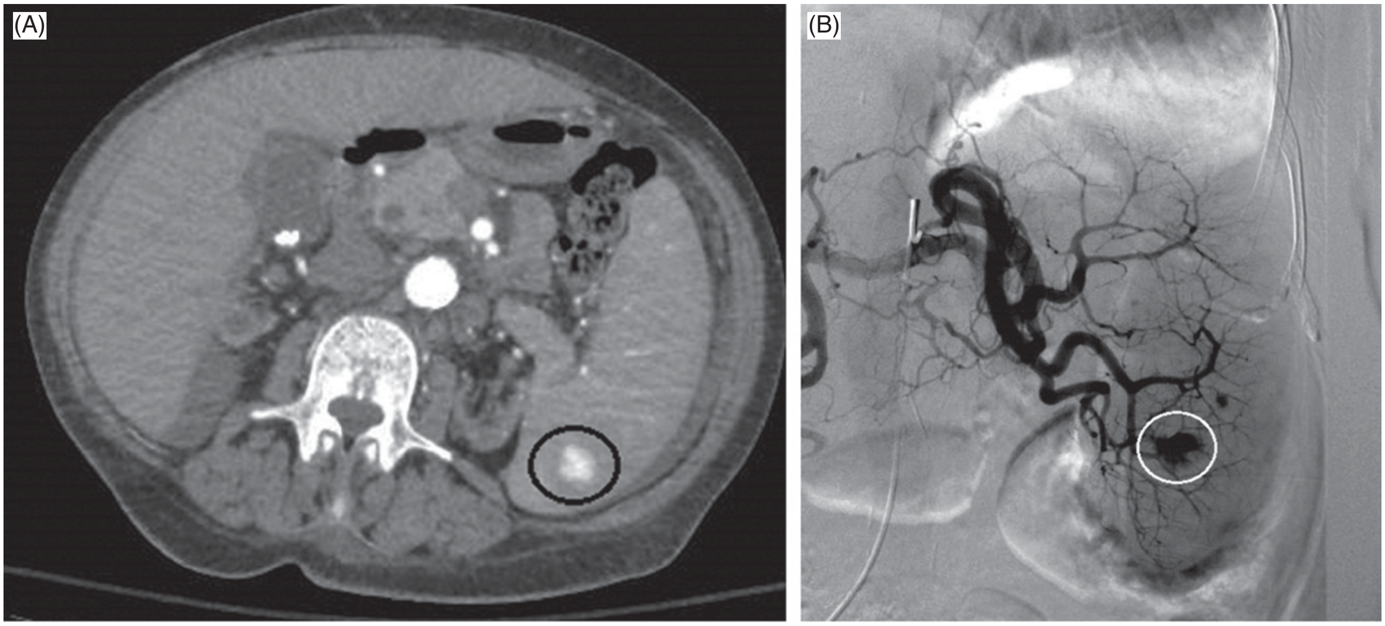


Figure 5.9 A,B CT scan showing a splenic aneurysm, following blunt trauma (A). Angiography confirms an intrasplenic pseudoaneurysm, which was successfully embolized (B).

Most isolated minor or moderate severity (grades I–III) splenic injuries can safely be managed nonoperatively (about 90% in children, 70% in adults), while severe injuries (grades IV or V) more often fail nonoperative management. The criteria for a trial of nonoperative management are hemodynamic stability, no signs of peritonitis, and no other indications for laparotomy. The abdominal CT scan is the standard method used to grade splenic injury, and high-grade injuries or those with high-risk features (hilar injury, false aneurysm, active contrast extravasation) may benefit from angioembolization or operative intervention. A dual-phase CT protocol can be useful to distinguish active extravasation of contrast from false aneurysm. Caution should be exercised in the selection of patients for nonoperative management in the presence of multiple associated severe injuries. Severe splenic injuries treated nonoperatively should be followed up by serial CT scans until there is satisfactory healing or absorption of any large hematomas. Subcapsular hematomas may rupture and bleed dangerously many days or weeks after injury (Figure 5.10).

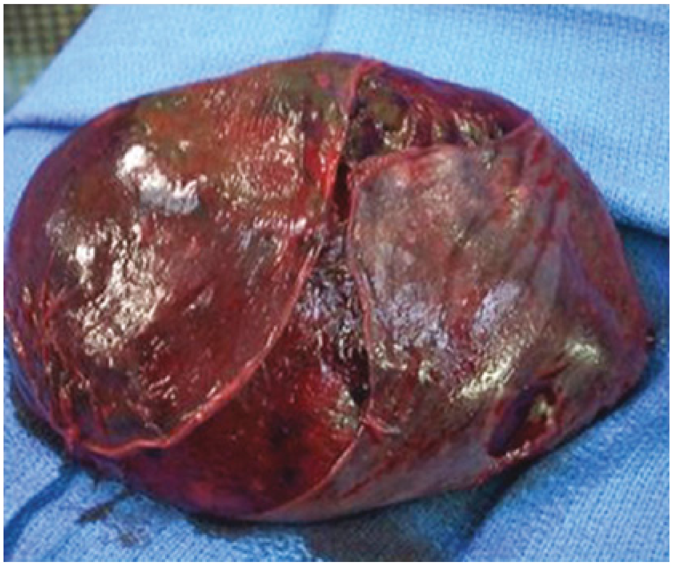


Figure 5.10 Operative specimen of a subcapsular splenic hematoma that ruptured many weeks after the injury.

Post-splenectomy complications may be systemic (post-splenectomy sepsis or thrombocytosis) or local (subdiaphragmatic abscess, pancreatic pseudocyst or fistula, gastroparesis, necrosis of the fundus of the stomach, thrombosis of the splenic vein, left pleural effusion, and atelectasis). To avoid post-splenectomy sepsis, vaccines targeting Neisseria meningitidis, Haemophilus influenzae, and Streptococcus pneumoniae should be administered to all patients. The vaccines are most effective if given before splenectomy. It is advisable that patients with high-grade injuries selected for nonoperative management receive the vaccine, in case the management fails and a splenectomy is needed. The splenectomized patient should be advised that medical care should be sought with the first signs or suspicion of any infections.

Liver Injuries

The clinical presentation of a liver injury may vary from minor pain in the right upper abdomen to hypovolemic shock. The diagnosis is suspected based on the physical examination and confirmed by CT scan or laparotomy. Most minor and moderate liver injuries (grades I–III), and even some severe injuries (grades IV and V) may be successfully managed nonoperatively, provided the patient is hemodynamically stable and there is no peritonitis. Hemodynamically stable patients with extravasation of contrast on CT scan, indicating bleeding or false aneurysm, are excellent candidates for angioembolization (Figure 5.11 A–F, Figure 5.12 A–C, Figure 5.13 A–C, Figure 5.14 A–C).

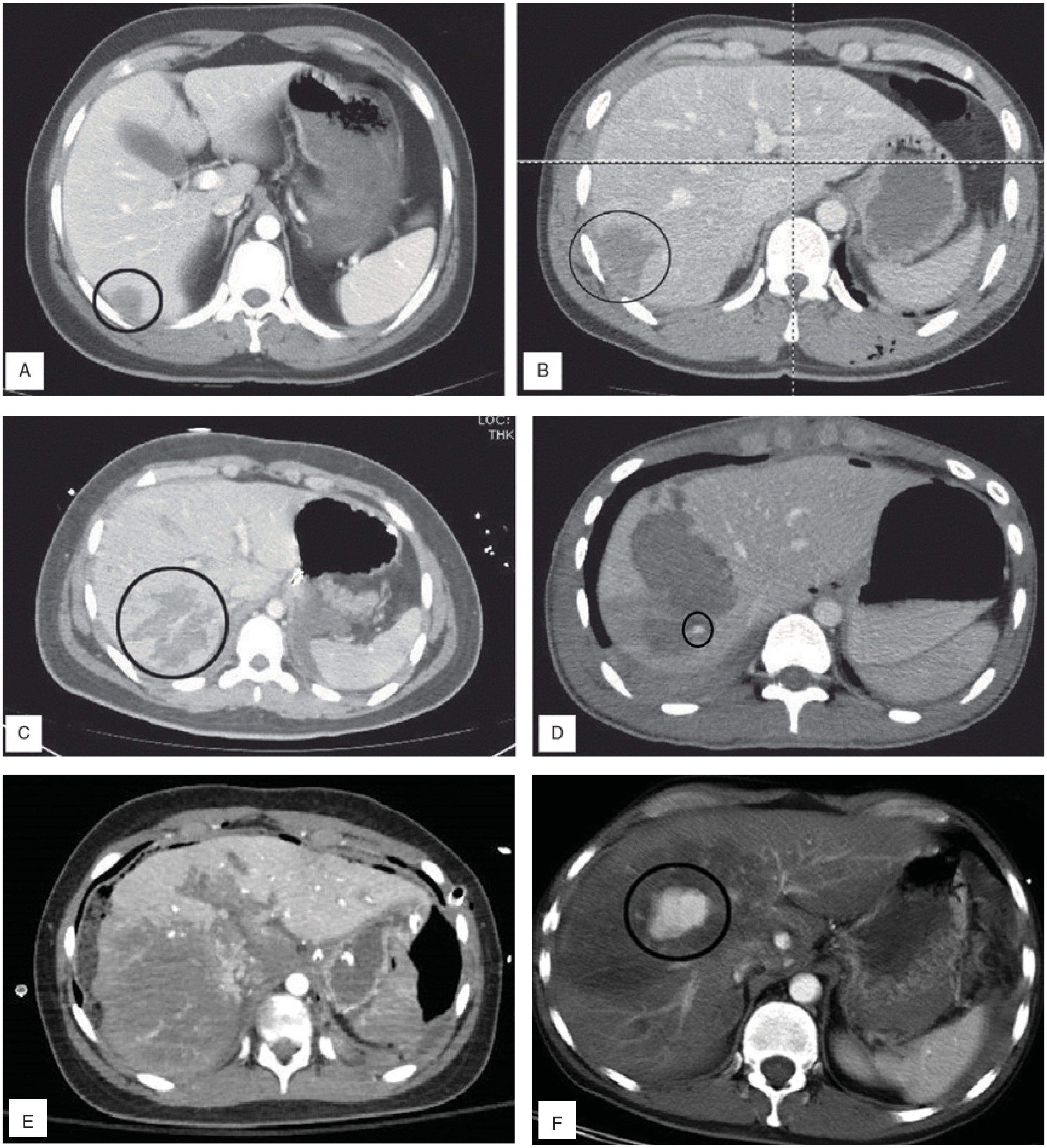


Figure 5.11 A–F CT scans of various grades of blunt liver trauma: grade I (A), grade II (B), grade III (C), grade IV (D) with false aneurysm (circle), grade V injury, with extension toward the inferior vena cava (E), grade V injury with active bleeding (circle; F).

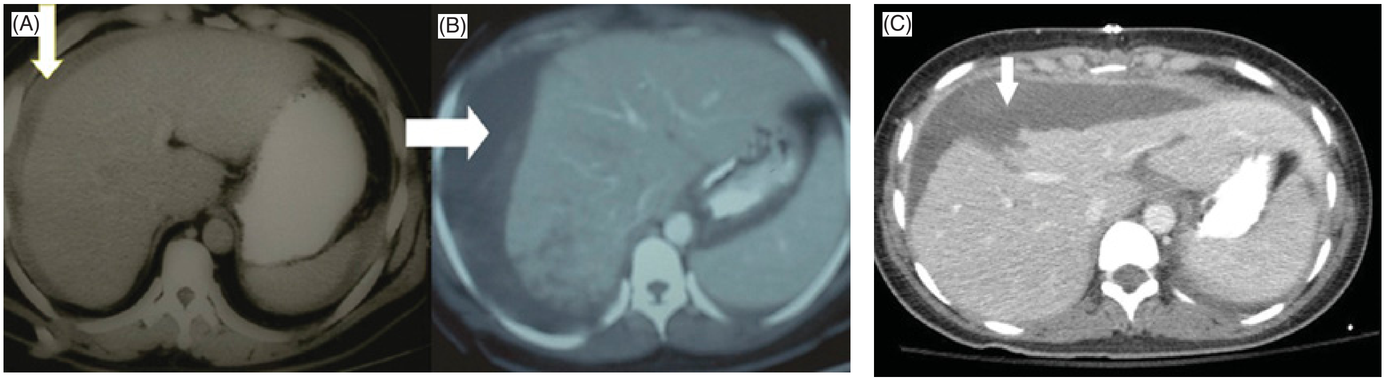


Figure 5.12 A–C CT scans of a small (A) and a large (B, C) subcapsular liver hematomas following blunt trauma.

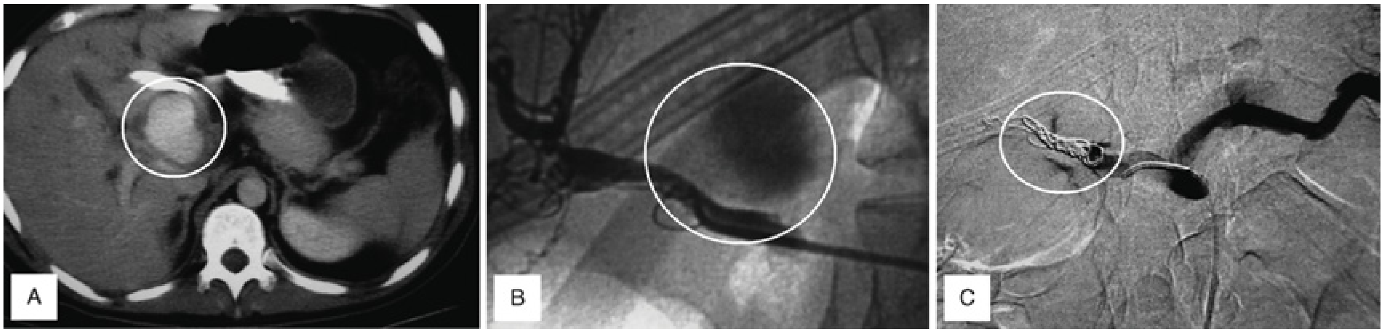


Figure 5.13 A–C CT scan shows a large pseudoaneurysm of the hepatic artery (A). The finding is confirmed by angiography (B), and the lesion is successfully managed with angioembolization (C).

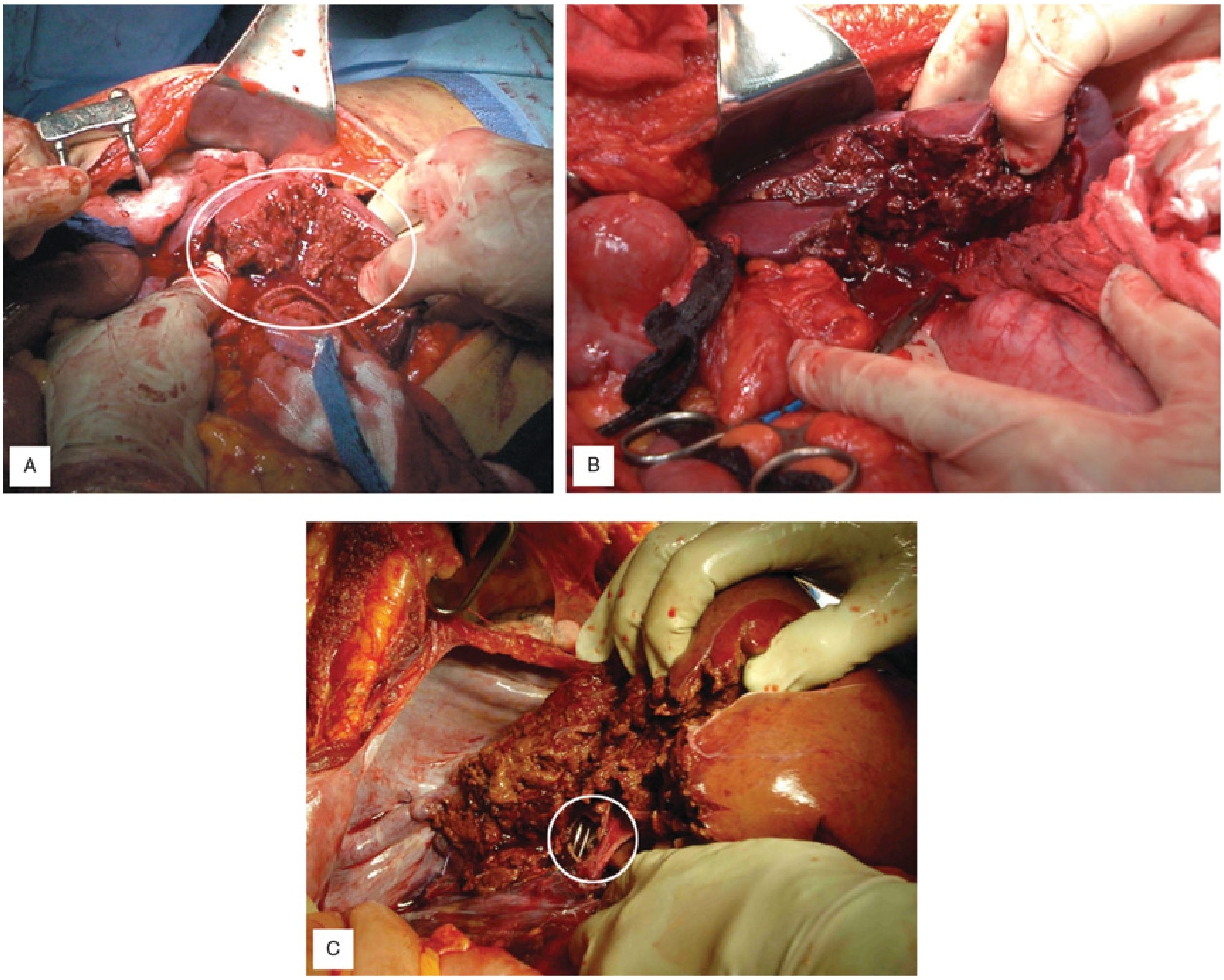


Figure 5.14 A–C Intraoperative appearance of severe liver injuries: grade III (A), grade IV (B), grade V (C). In the grade V injury, there is avulsion of the hepatic veins and tear of the inferior vena cava (circle).

Posttraumatic liver complications include liver abscess, biloma, biliary leak, liver necrosis, false aneurysm, and hemobilia (bleeding into the biliary tree). Most of these complications can be managed with percutaneous drainage, endoscopic retrograde cholangiopancreatography (ERCP) stenting, or angiographic embolization (Figure 5.15 A,B, Figure 5.16 A,B).

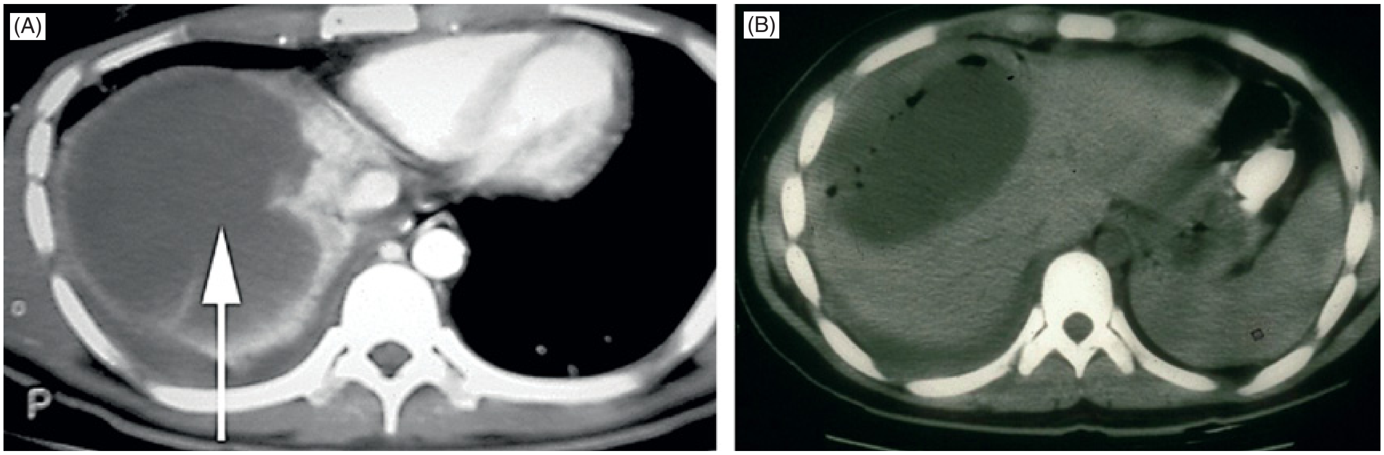


Figure 5.15 A,B Large bilomas many weeks after blunt severe liver injury. The patients were successfully managed with percutaneous drainage.

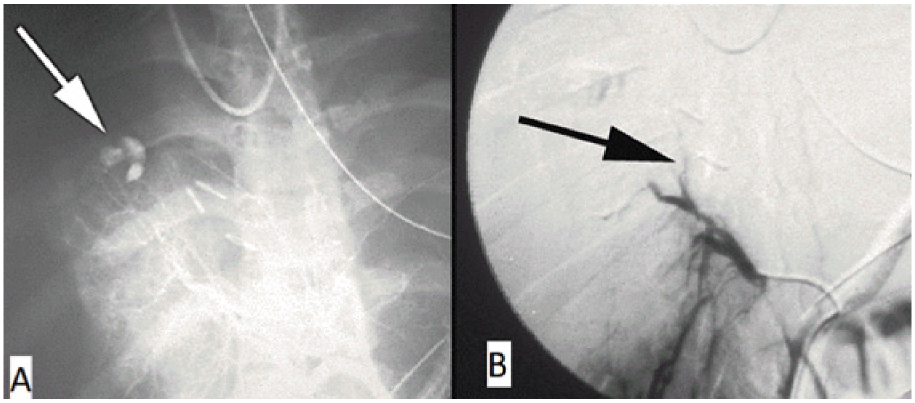


Figure 5.16 A,B This patient presented with a copious amount of blood in the nasogastric tube soon after a grade IV liver injury. This finding is highly suspicious of hemobilia. Angiogram confirming pseudoaneurysm and hemobilia (A), which was successfully embolized (B).

Pancreatic Injuries

Most pancreatic injuries due to blunt trauma occur at the neck of the pancreas, caused by crushing of the organ against the spine. The clinical presentation may vary from mild epigastric pain to peritonitis. The diagnosis is suspected from the history of abdominal trauma and confirmed by specific investigations or at operation. The initial serum amylase or lipase may be elevated in about 70% of patients, and serial measurements should be performed in suspected cases. The CT scan is usually diagnostic, although the early CT scan may not show the injury. It is essential that in suspected cases a repeat CT scan be performed 6–8 hours after the initial investigation. ERCP or MRCP may be useful in determining any damage to the duct (Figure 5.17 A,B, Figure 5.18).

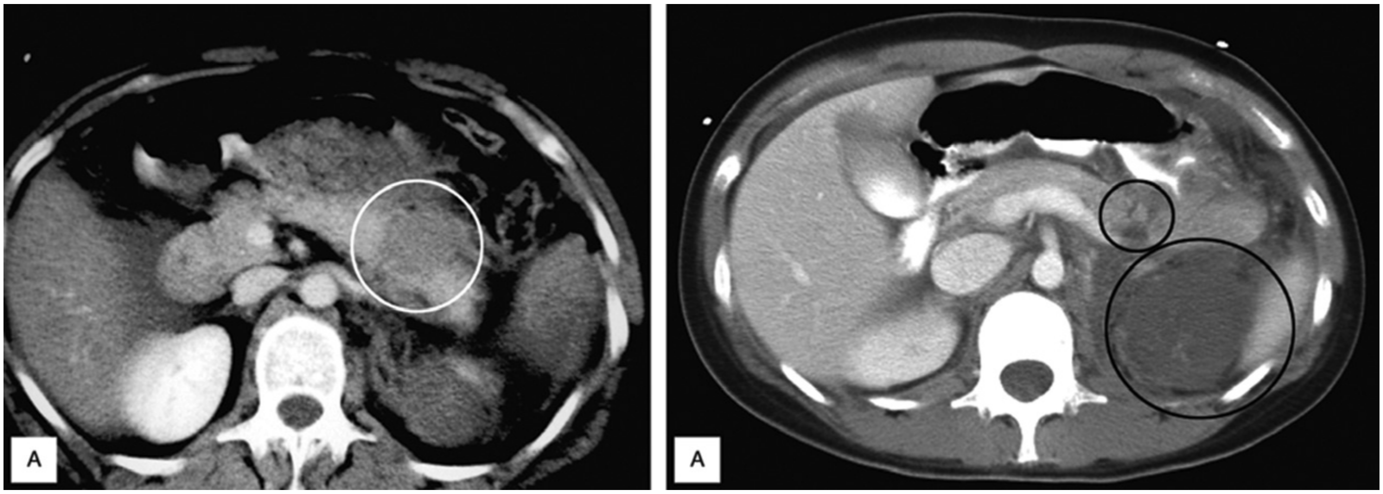


Figure 5.17 A,B CT demonstrating distal pancreatic transection (circle; A). CT scan shows distal pancreatic injury (small circle) and no contrast uptake by the left kidney, due to thrombosis of the left renal artery (large circle; B).

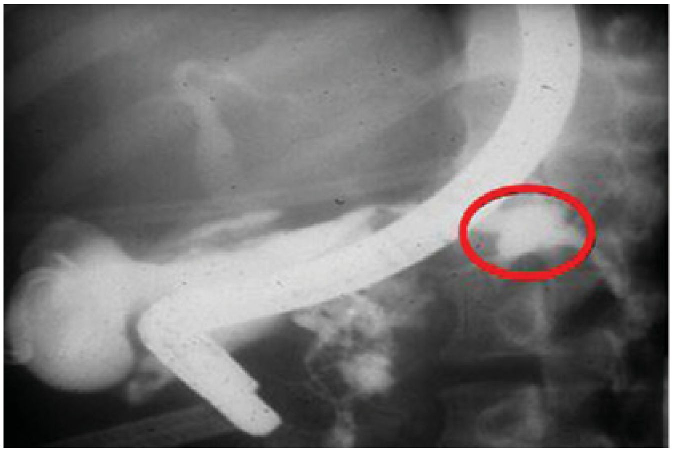


Figure 5.18 ERCP demonstrates distal pancreatic injury with partial transection and extravasation (arrow).

Superficial pancreatic injuries not involving the duct can be managed successfully without operation. However, in the presence of clinical signs of peritonitis or hemodynamic instability, an operation should be performed. Intraoperatively, in the presence of distal ductal injury (to the left of the superior mesenteric vessels), a distal pancreatectomy is the procedure of choice.

Patients with pancreatic duct injury in the head of the pancreas may be managed nonoperatively if the patient is hemodynamically stable and there are no signs of peritonitis. Some of these patients may benefit from an ERCP-guided pancreatic stent. In severe injuries to the head of the pancreas or severe combined pancreatoduodenal injuries, a Whipple's pancreatoduodenectomy may be necessary.

Local complications directly related to the injury include pancreatic pseudocyst, pancreatitis, abscess, and fistula. Many of these complications can be managed nonoperatively or by percutaneous drainage or ERCP stenting (Figure 5.19 A–D).

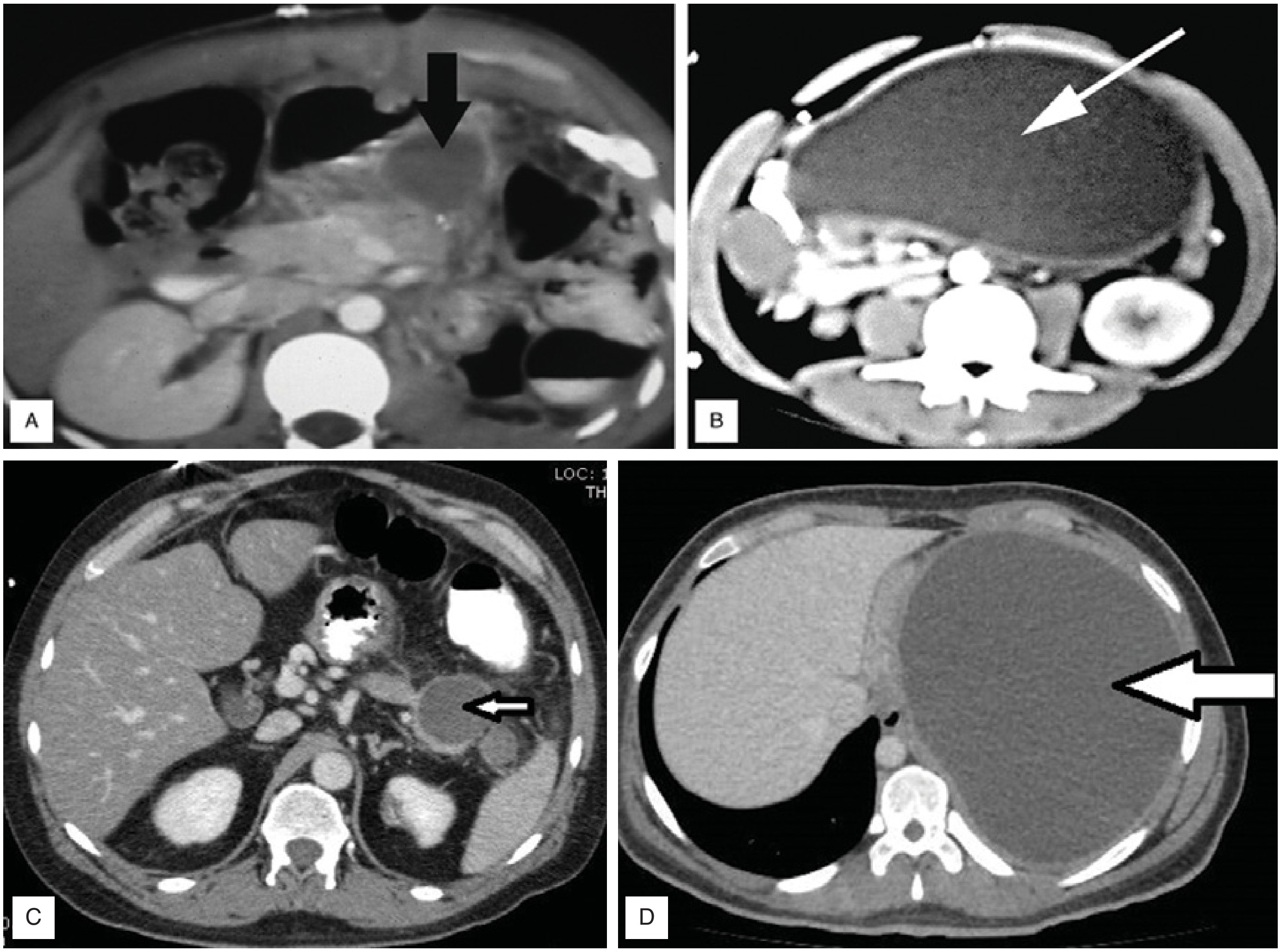


Figure 5.19 A–D Posttraumatic pancreatic pseudocysts presenting many weeks after the initial injury. Small pseudocyst successfully observed (A). Large pseudocyst following blunt trauma, successfully managed with percutaneous drainage (B). Pseudocyst in the body of the pancreas following blunt trauma. The patient was successfully managed nonoperatively (C). Large pseudocyst in the tail of the pancreas, successfully managed with percutaneous drainage (D).

Renal Injuries

A kidney injury may manifest clinically with pain in the flank and microscopic or gross hematuria. Gross hematuria will be present only if there is a calyceal tear. An abdominal CT scan with intravenous contrast is the most useful diagnostic investigation. The CT scan provides information about the site and size of parenchymal injuries, and shows renovascular injuries or evidence of active bleeding or false aneurysm (Figure 5.20 A,B, Figure 5.21 A,B, Figure 5.22 A,B).

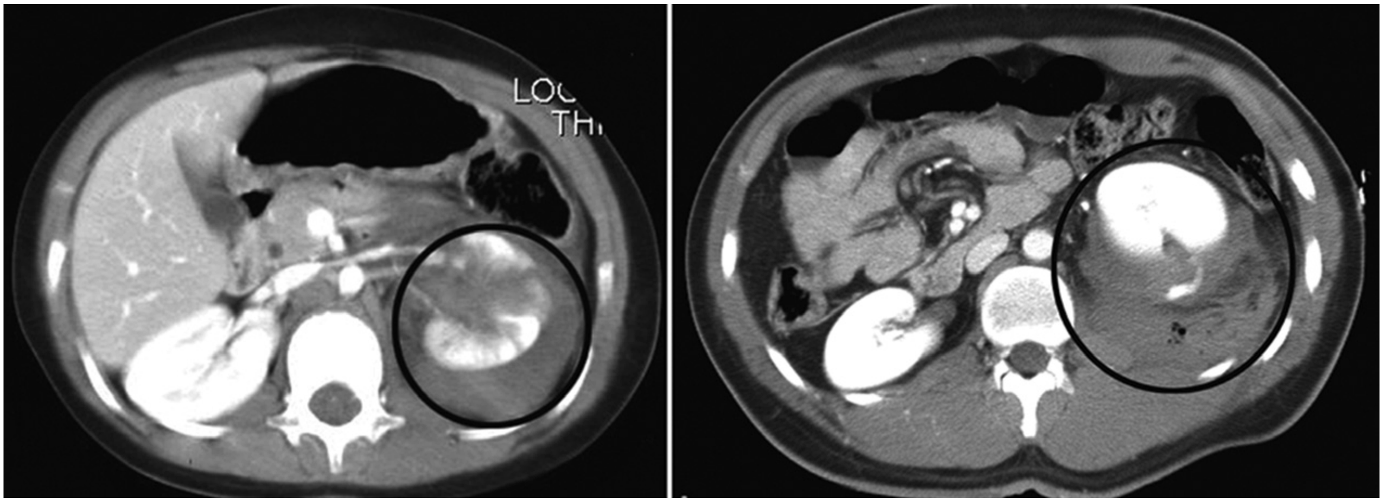


Figure 5.20 A,B CT scan demonstrating high-grade kidney injury (A) with large perinephric hematoma (B).

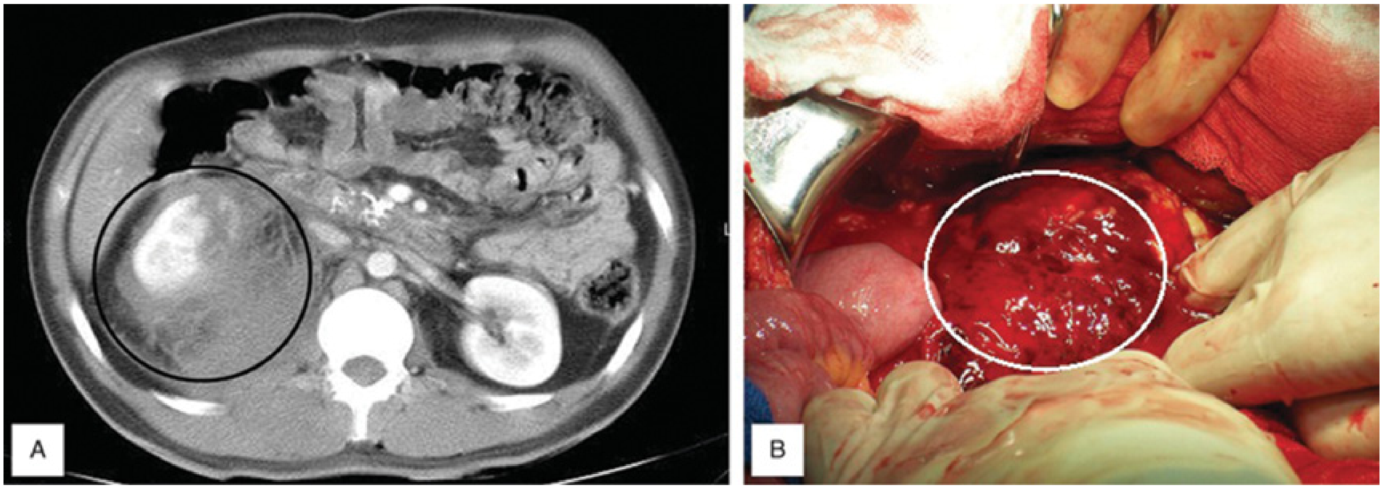


Figure 5.21 A,B CT scan shows a severe right kidney injury with a large surrounding hematoma (A). Intraoperative appearance of the renal hematoma (B).

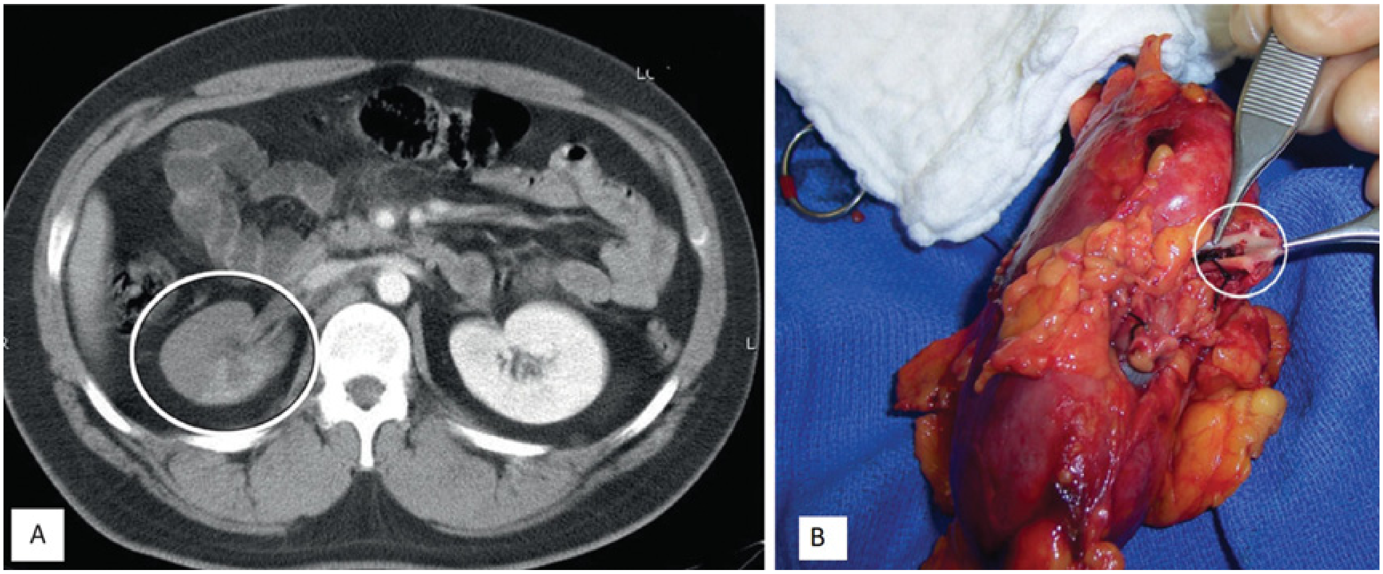


Figure 5.22 A,B CT scan of patient with blunt renal artery thrombosis (no contrast uptake), without any parenchymal injury (A). Due to prolonged ischemia, a nephrectomy was performed. The operative specimen shows a clot in the renal artery (B).

Catheter angiography with angioembolization has a major therapeutic role in cases with active bleeding, false aneurysms, or arteriovenous fistula on CT scan. Patients with renal artery thrombosis may benefit from angiographically placed stent-grafts.

The vast majority of blunt renal injuries can be safely managed nonoperatively. Attempts to explore and repair all renal injuries may result in loss of the kidney. Renal artery thrombosis is almost always diagnosed on contrast CT scan and shows as lack of contrast uptake by the kidney (Figure 5.23 A–E, Figure 5.24 A,B).

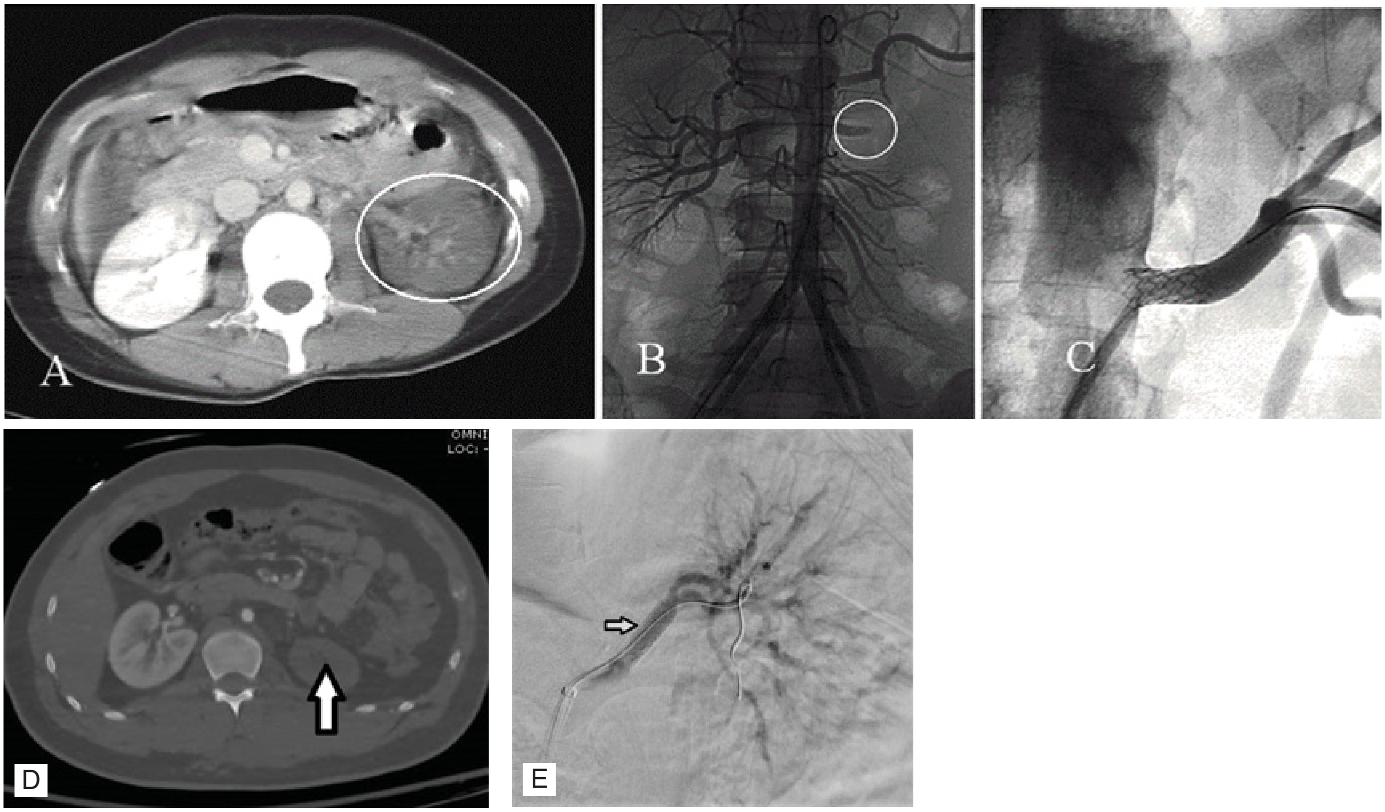


Figure 5.23 A–E CT scan following blunt trauma due to fall from a height. There is no contrast uptake by the left kidney, due to renal artery thrombosis (A). Angiography confirms occlusion of the left renal artery (B). The arterial thrombosis was successfully managed with an angiographically placed stent (C). In another patient, CT showing no uptake by the left kidney (arrow) due to renal artery thrombosis, following blunt trauma (D). Successful revascularization of the artery with an angiographically placed stent (arrow; E).

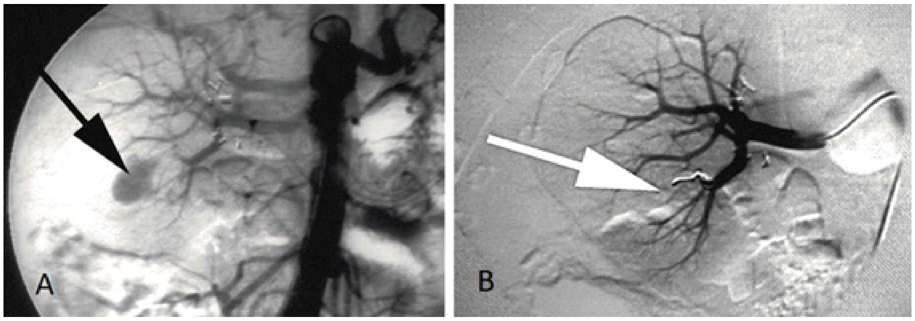


Figure 5.24 A,B Blunt trauma with false aneurysm in the right kidney (A). Successful coil angioembolization of the aneurysm (B).

If the diagnosis is made within a few hours of the injury, the injured artery can successfully be managed with an angiographically placed stent. However, prolonged ischemia causes permanent damage to the kidney and precludes revascularization.

Complications related to renal injury include false aneurysm, arteriovenous fistula, urinoma, and late hypertension.

Bladder Injuries

Bladder injuries are usually due to pelvic fractures or blunt abdominal trauma with a full bladder. The rupture may be intraperitoneal or extraperitoneal. The patient may present with hematuria or inability to pass urine, and the diagnosis is confirmed by plain or CT cystogram.

All intraperitoneal ruptures need operation and repair. Most extraperitoneal ruptures can be managed nonoperatively with transurethral catheter drainage for about 10 days (Figure 5.25 A–C, Figure 5.26 A,B, Figure 5.27 A–C).

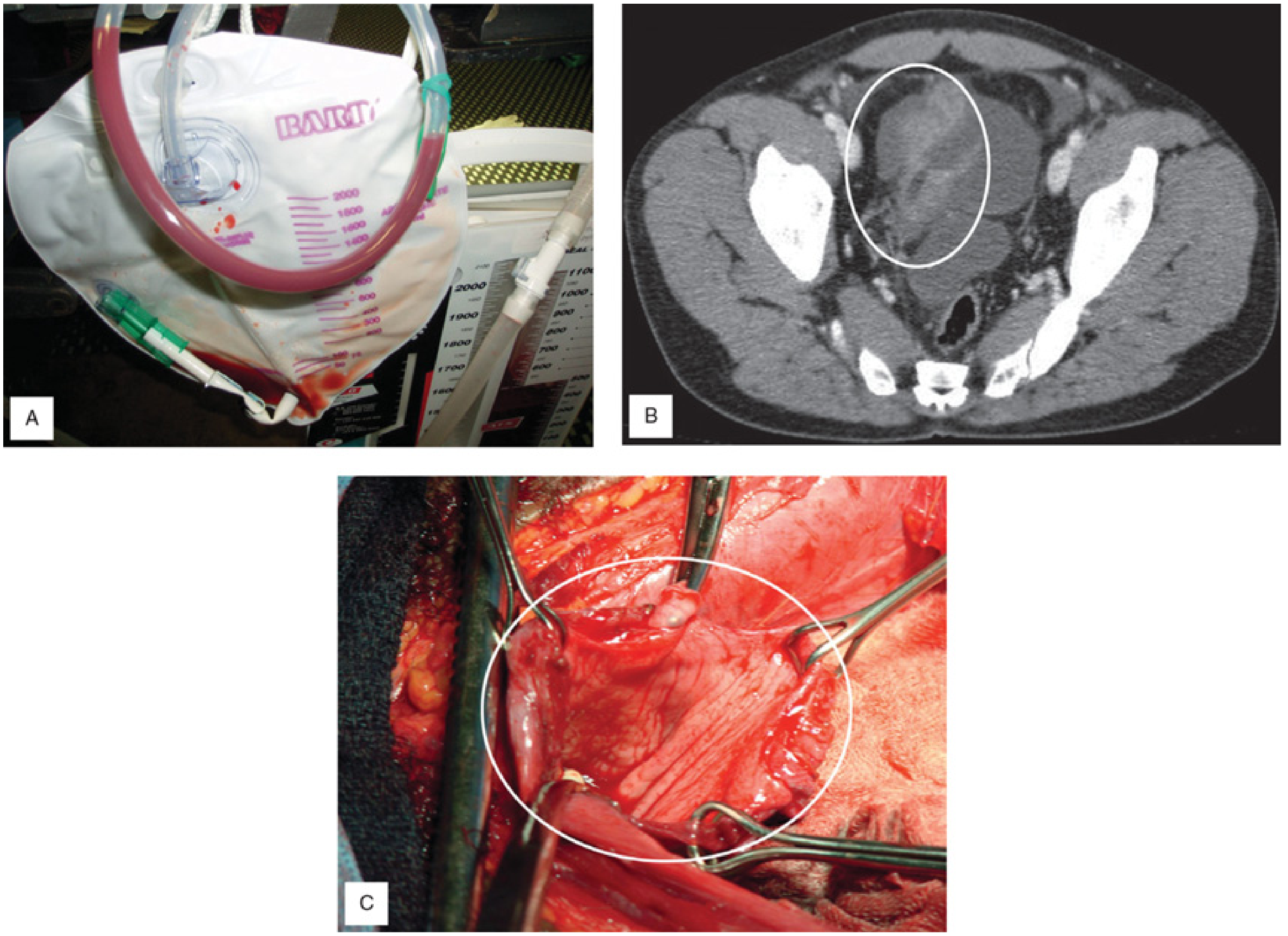


Figure 5.25 A–C Intraperitoneal rupture of the bladder. The patient presented with lower abdominal pain and gross hematuria following blunt trauma (A). CT cystogram showing intraperitoneal bladder rupture (circle; B). Intraoperative appearance of the rupture of the dome of the bladder (circle; C).

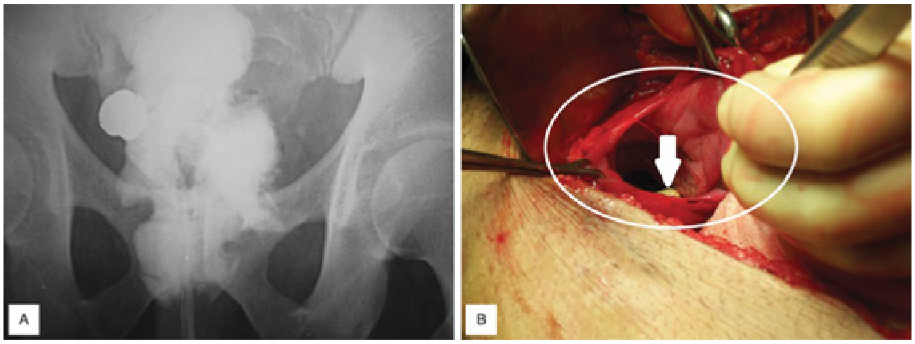


Figure 5.26 A,B Intraperitoneal rupture of the bladder. Cystogram shows intraperitoneal rupture of the bladder (A). Intraoperative appearance of the bladder rupture and a visible Foley catheter tip (arrow; B).

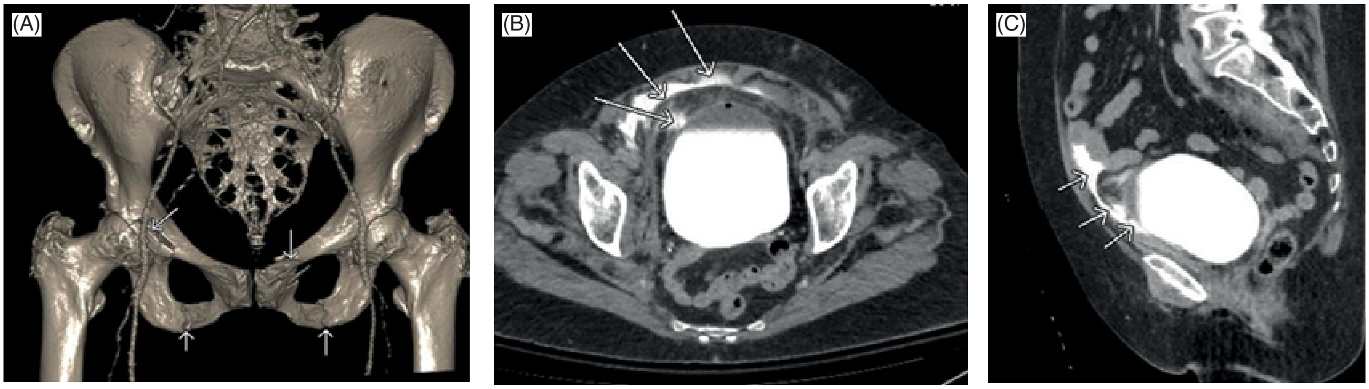


Figure 5.27 A–C Auto versus pedestrian injury, patient presenting with gross hematuria. CT scan of the pelvis showing multiple pelvic fractures (arrows; A). CT cystogram showing extraperitoneal rupture (arrows; B, C). Extraperitoneal bladder ruptures can be managed nonoperatively, with Foley catheter drainage of the bladder for 10–14 days.

Urethral Injuries

Urethral injuries occur almost exclusively in males, and they are usually associated with anterior pelvic fractures or falls resulting in straddle injuries. The clinical presentation may include blood at the urethral meatus, a scrotal or perineal hematoma, inability to pass urine, floating prostate on rectal examination, and urine extravasation in the scrotum. The diagnosis is confirmed by urethrogram (Figure 5.28 A,B, Figure 5.29 A–C, Figure 5.30 A,B).

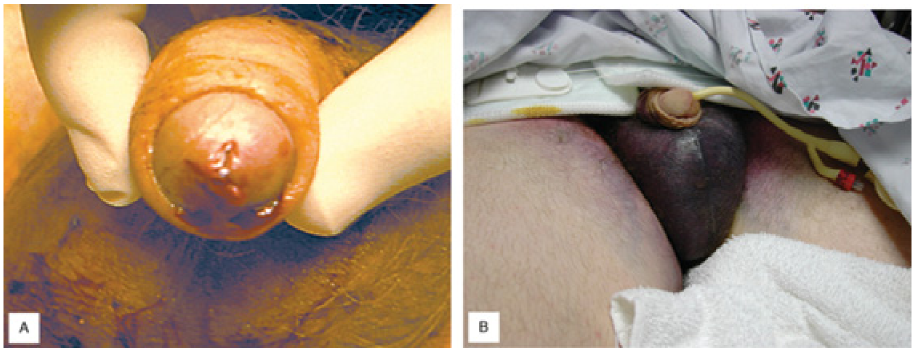


Figure 5.28 A,B Clinical signs of rupture of the urethra: blood at the meatus (A) or scrotal hematoma (B) in patients with pelvic fractures or after straddle injury are highly suspicious of urethral rupture. These patients should be evaluated by urethrogram.

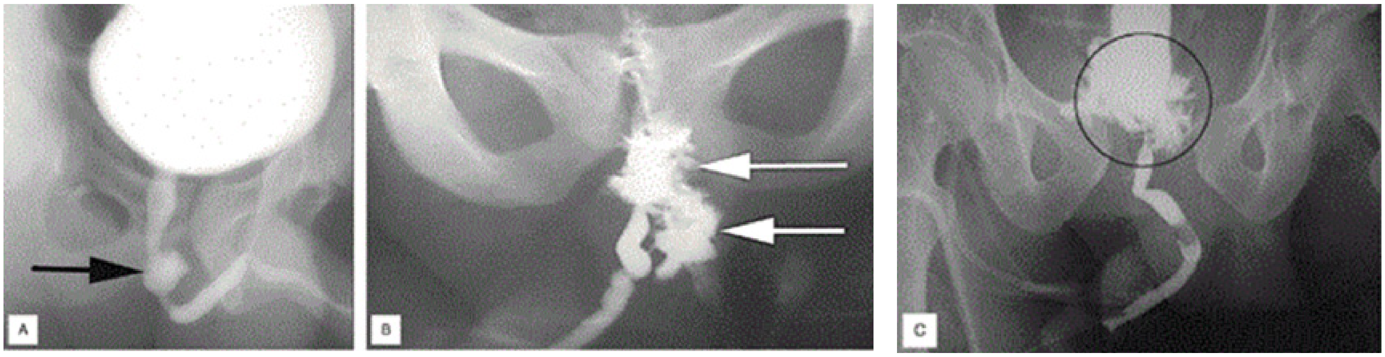


Figure 5.29 A–C Voiding cysto-urethrograms showing rupture of the urethra (arrows; A–C).

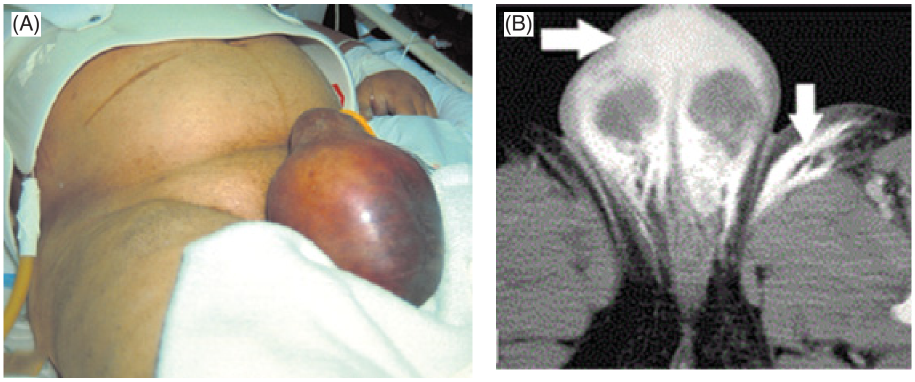


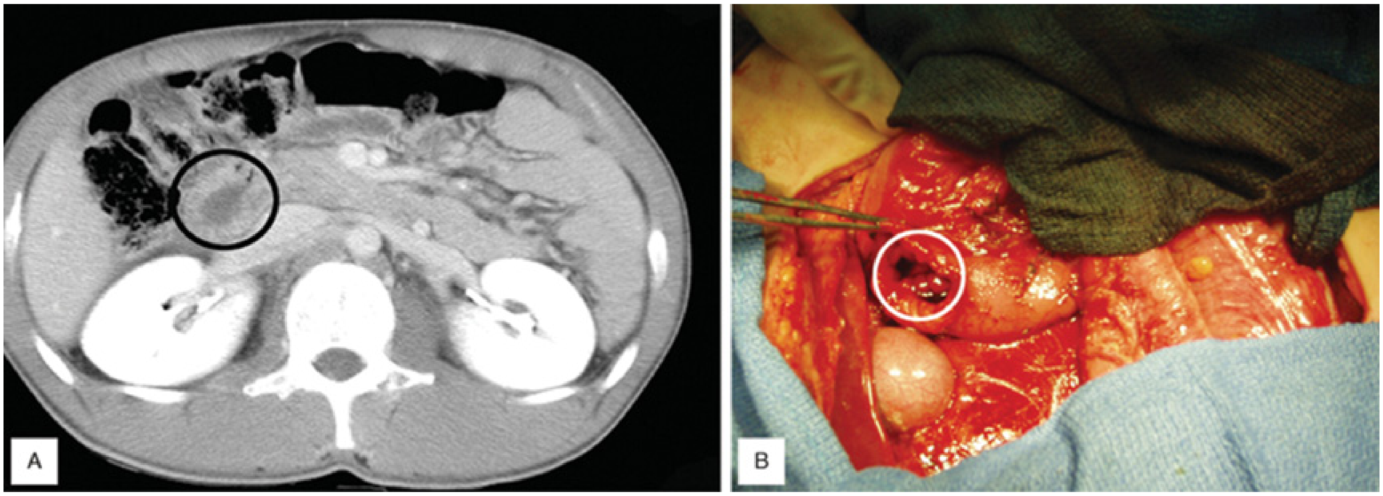
Figure 5.30 A,B Patient with pelvic fracture and massive scrotal hematoma (A). CT cystogram showing massive extravasation of contrast in the scrotum and extraperitoneal tissues secondary to posterior urethral disruption (B).

In suspected urethral injuries, avoid transurethral catheterization until a retrograde urethrogram shows integrity of the urethra. Experienced physicians may attempt careful insertion of the urethral catheter without using any force. In the majority of cases, drainage of the bladder with a transurethral or supra-pubic catheter provides the definitive management. An alternative is immediate endoscopic realignment, with a Foley catheter placement by a urologist. Emergency operative repair of the urethra is not advocated because of the inferior results.

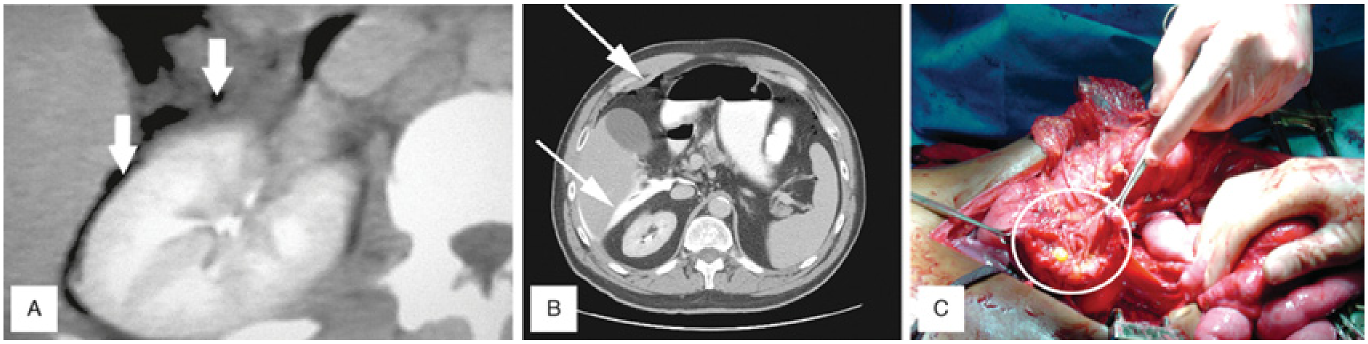
Duodenal Injuries

Blunt duodenal trauma may occur as a result of direct trauma to the abdomen that compresses the duodenum against the vertebral column or following deceleration injuries. The injury often involves the retroperitoneal part of the duodenum. The clinical examination may be difficult due to subtle signs and symptoms because of the retroperitoneal location of the rupture. The initial presentation may include minor epigastric tenderness and tachycardia, and signs of peritonitis may appear a few hours later.

Laboratory tests are of little help in the early diagnosis of duodenal rupture. The serum amylase may be elevated and should be monitored at 4–6-hour intervals. Abdominal X-ray may show retroperitoneal air, especially around the upper pole of the right kidney. CT scan with contrast is the imaging modality of choice in the acute setting (Figures 5.31 A,B, Figures 5.32 A–C).



Figures 5.31 A,B Blunt trauma to duodenum. CT demonstrates duodenal wall thickening with intramural air (A). Intraoperative appearance of duodenal perforation (B).



Figures 5.32 A–C CT scan shows free air around the right kidney, due to retroperitoneal rupture of the duodenum (A). CT scan with oral contrast shows contrast extravasation between the kidney and the liver (lower arrow). Note the tiny bubble of free gas under the anterior abdominal wall (upper arrow) (B). Operative appearance of a near-complete transection of the duodenum (circle; C).

Early diagnosis and surgical repair of duodenal perforations remains the cornerstone for a good outcome. Common postoperative complications include local infection and fistula formation. Patients with duodenal hematoma on CT scan should be evaluated with oral gastrografin studies to rule out perforation. In the absence of perforation most of these hematomas, especially in children, can be managed nonoperatively (Figure 5.33).

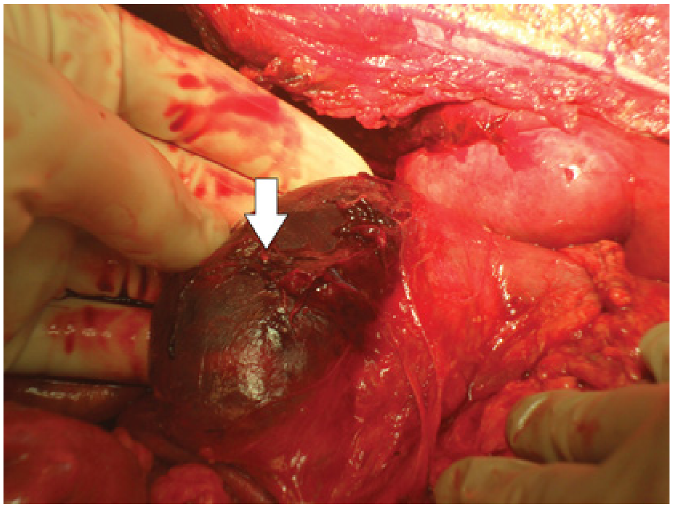


Figure 5.33 Intraoperative appearance of a large duodenal hematoma (arrow). All duodenal hematomas identified during laparotomy should be explored to rule out underlying perforation.

Small Bowel Injuries

Small bowel perforation occurs in about 3% of blunt abdominal trauma patients (Figure 5.34 A–D). The diagnosis can be difficult, especially in unevaluable multi-trauma patients, and is one of the most commonly missed injuries. A seat-belt sign is a highly suspicious finding that should alert the physician to the possibility of bowel injury.

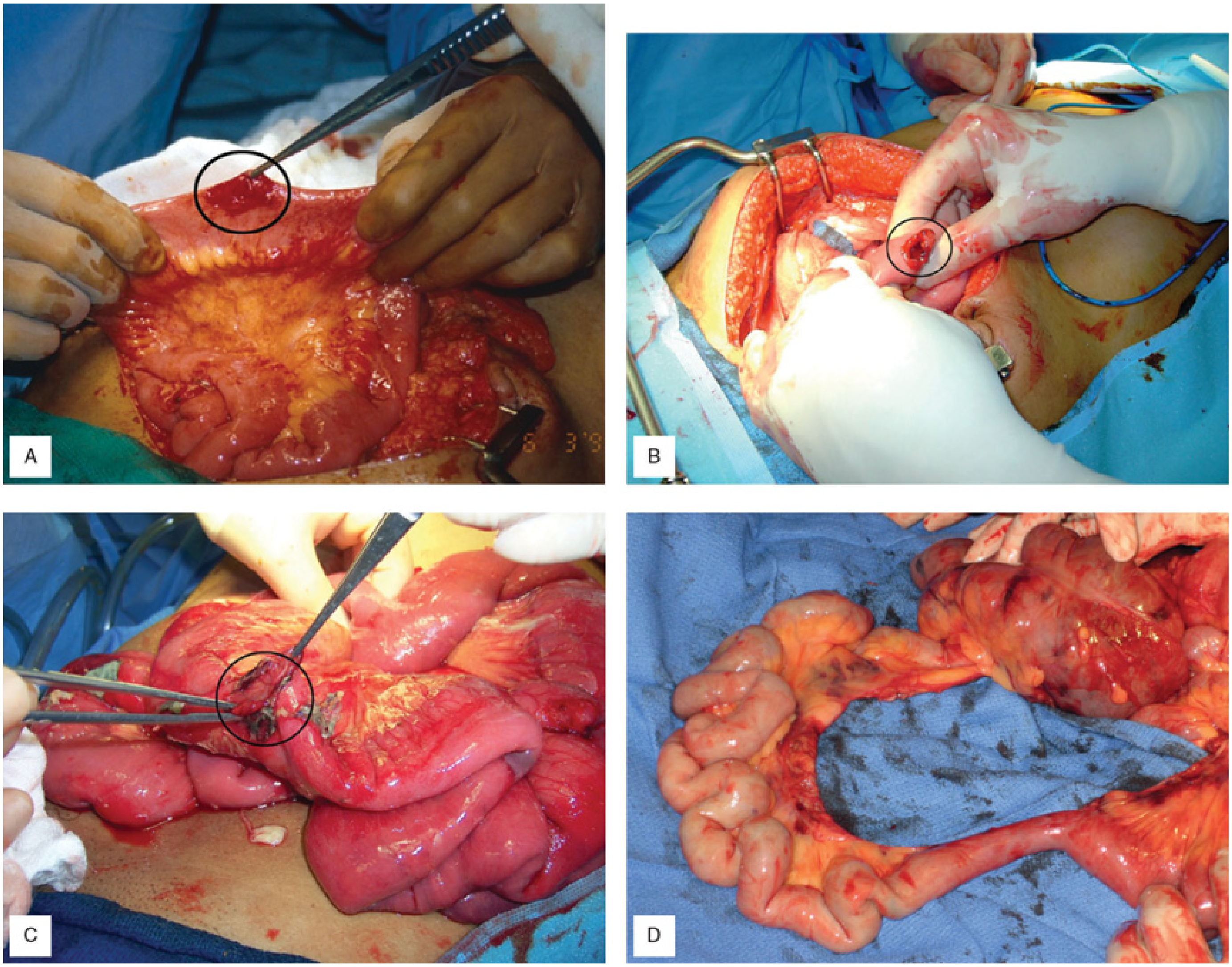


Figure 5.34 A–D Blunt small bowel injury. Perforation of the small bowel, usually at the antimesenteric border, is the result of transient closed-loop formation and high intraluminal pressure (A, B). Note the inflammation and pseudomembranes (circle) in delayed diagnosis (C). Small bowel mesenteric tear, "bucket handle" type injury, is the result of rapid deceleration forces (D).

The plain abdominal X-ray is usually of little help because in most cases it is nondiagnostic and fails to show any free intraperitoneal air. The abdominal CT scan may be diagnostic in about 70% of cases, as it may show small amounts of free air or thickening of the bowel wall or mesentery (Figure 5.35 A–C). The presence of free fluid without evidence of solid organ injury is a highly suspicious finding and requires careful close monitoring and a low threshold for exploration. In suspicious cases, serial clinical examinations, white blood cell monitoring, and a follow-up CT scan should be carried out.

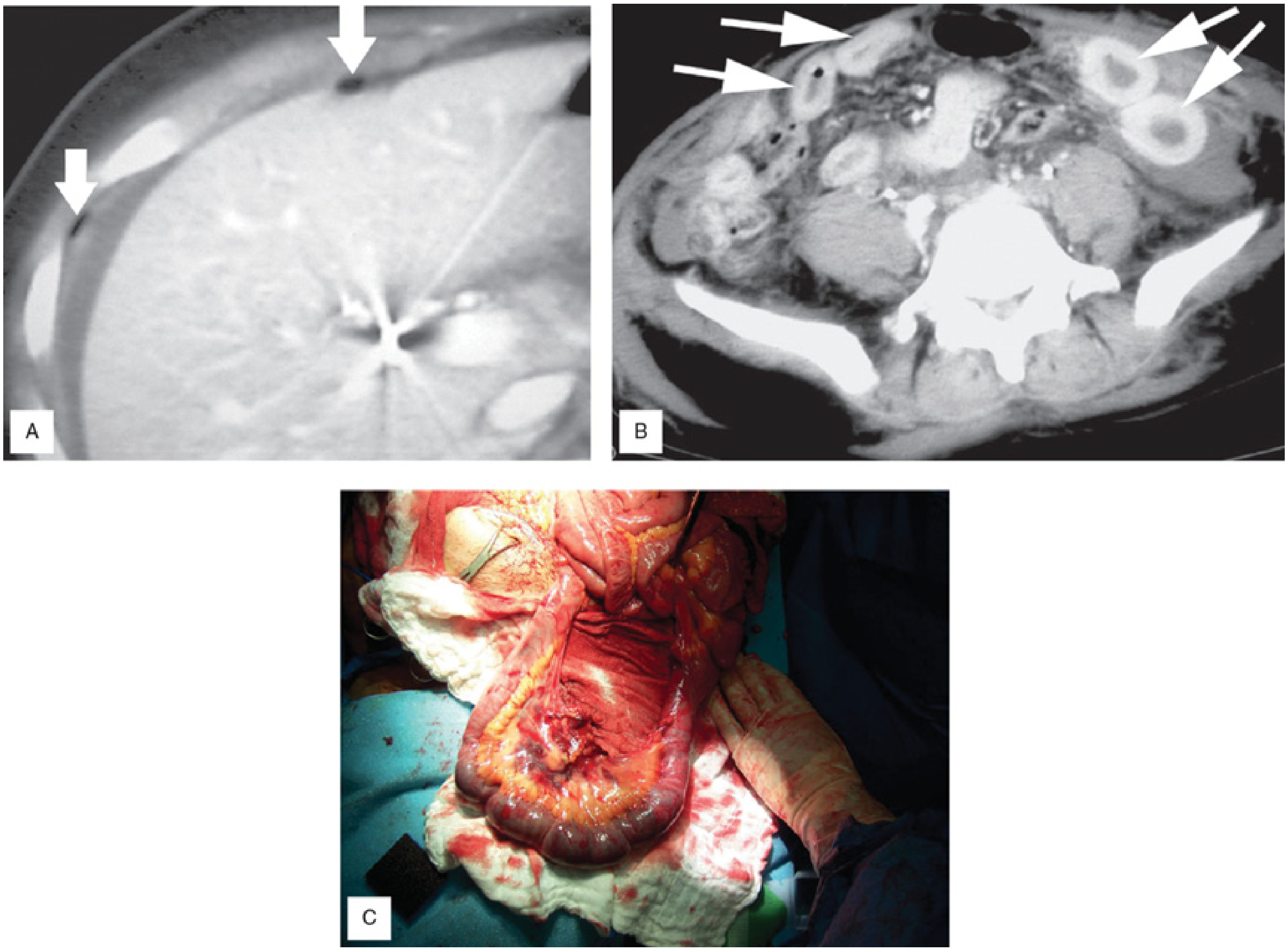


Figure 5.35 A–C CT scan findings in small bowel injury. Small amounts of free intraperitoneal gas (arrows) may be found in many cases (A). Thickening of the small bowel wall (arrows) may be found, especially if the CT scan is taken a few hours after the injury (B). Intraoperative photograph of small bowel "bucket handle" avulsion injury with ischemia, following high-speed motor vehicle collision (C).

Colorectal Injuries

Blunt colorectal trauma may occur in high-speed deceleration collisions or in association with pelvic fractures. Deceleration injuries usually cause avulsion of the mesocolon and ischemia of the colon, while in pelvic fractures there is sometimes free perforation of the rectosigmoid. The diagnosis is usually easy in intraperitoneal injuries because of the presence of peritonitis. However, in extraperitoneal rectal injuries, the physical findings may be unremarkable, and the diagnosis may be delayed. The diagnosis of rectal injury should be suspected in severe pelvic fractures, especially in the presence of blood on rectal examination. A gastrografin enema and a careful sigmoidoscopy without excessive insufflation can confirm the injury. Abdominal CT scan usually shows large amounts of free intra-abdominal gas. Early operation is essential to reduce the risk of sepsis (Figure 5.36 A,B).

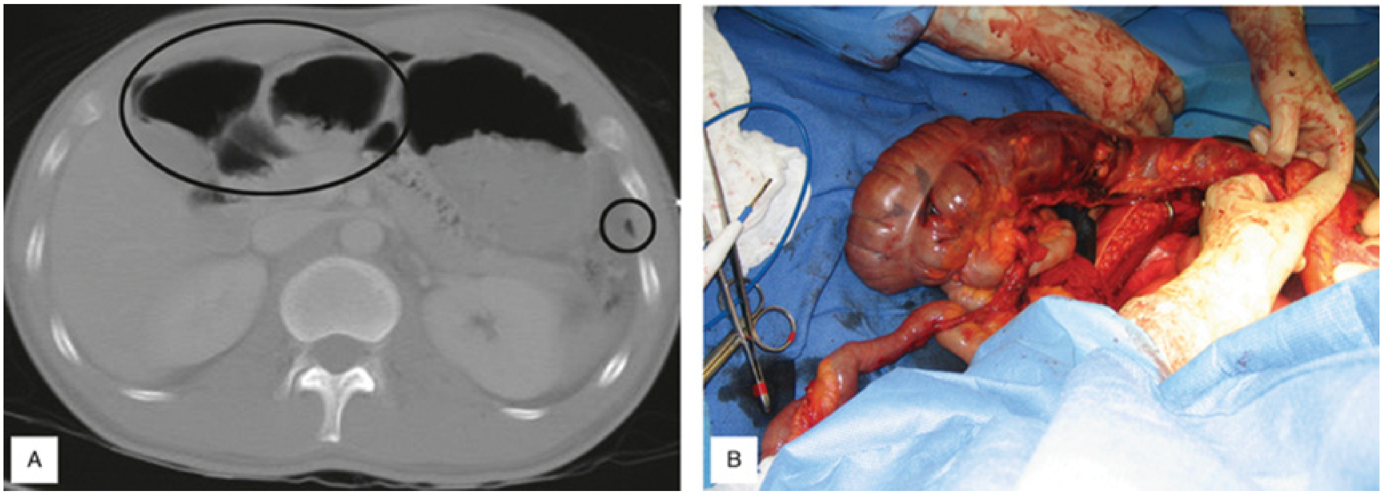


Figure 5.36 A,B Abdominal CT shown a large amount of free intraperitoneal gas (circle) following a motor vehicle collision (A). Intraoperative appearance of colonic "bucket handle" avulsion injury with ischemia and perforation (B).

Penetrating Abdominal Trauma

Introduction

The initial evaluation of penetrating abdominal trauma is very different from the evaluation of blunt trauma. Penetrating trauma, especially gunshot wounds, is much more likely to be associated with intestinal or life-threatening major vascular injuries. Knife injuries to the anterior abdomen are associated with significant intra-abdominal injuries in about 50% of patients. In gunshot wounds, about 80% of cases have major injuries requiring surgical repair.

Clinical Examination

Physical examination is usually reliable in identifying or highly suspecting significant intra-abdominal injuries. The physician must remember that patients with a short prehospital time may seem hemodynamically stable despite severe active intra-abdominal bleeding, and thus serial examinations are critical in the initially asymptomatic patient. Tachycardia and elevated diastolic pressure (narrow pulse pressure) are suspicious markers of bleeding, and these patients should be reevaluated clinically every few minutes during admission.

Investigations

1. FAST can identify patients with hemoperitoneum or cardiac tamponade. Hemoperitoneum in a hemodynamically stable patient with no peritonitis should be followed by a CT scan.
2. Chest X-ray should be obtained in selected patients with stab wounds or gunshot wounds with suspected thoracic involvement. The X-ray may show a hemopneumothorax, an elevated diaphragm, free air under the diaphragm, or foreign body.
3. Abdominal X-rays have no role in stab wounds to the abdomen, except to identify retained foreign bodies, and they should rarely be requested. However, if time permits, they should be obtained for all torso gunshot wounds and in patients with suspected spine or pelvic fractures.
4. CT scan with IV contrast is very useful in evaluating patients with gunshot wounds who are hemodynamically stable and no indications for immediate laparotomy. The CT scan may show a bullet tract away from any major structures and avoid an unnecessary operation. Most trauma centers practice selective nonoperative management of gunshot wounds to the liver, kidney, or spleen in carefully selected patients who are hemodynamically stable and have no signs of peritonitis. CT scanning of these patients can demonstrate the extent of the solid organ injury and may identify false aneurysms or active bleeding.
5. Catheter angiography with angioembolization plays an important therapeutic role in patients with liver, kidney, or spleen injuries when the CT scan is suspicious for false aneurysms, arteriovenous fistula, or active bleeding. Similarly, in patients who have undergone damage control operations for severe liver injuries or complex pelvic fractures, angiographic embolization of any remaining bleeding vessels may be life-saving.
6. Diagnostic laparoscopy has a definitive role in the evaluation of suspected diaphragmatic injuries (see Chapter 4, Thoracic Injury).

General Management

One of the most important goals in managing penetrating abdominal injuries is to avoid nontherapeutic laparotomies and yet not miss any significant injuries. Patients presenting with hemodynamic instability or signs of peritonitis require an emergency operation without any delay. Patients with minimal or equivocal abdominal signs should be monitored with serial clinical examinations and continuous hemodynamic monitoring. Further investigations, such as CT scan, serial white blood cell count, or diagnostic laparoscopy, should be performed in appropriate cases. If the patient develops hemodynamic instability or signs of peritonitis, an exploratory laparotomy should be performed. Patients who remain asymptomatic are discharged after 24–48 hours of observation. The selective nonoperative management policy can be applied in both stab wounds and gunshot wounds, provided the patient is clinically evaluable.

Tips and Pitfalls

- Patients with short prehospital times may seem hemodynamically stable on admission, despite significant active intra-abdominal bleeding. Once a decision for laparotomy has been made, no time should be wasted for further investigations.
- Penetrating injuries to the diaphragm are usually clinically and radiologically silent. All patients with left thoracoabdominal injuries who are asymptomatic should be evaluated by diagnostic laparoscopy.
- Patients with associated severe head or spinal cord injuries and those undergoing general anesthesia for an extra-abdominal operation cannot be evaluated clinically. In these groups of patients, the presence of a deep penetrating abdominal wound should be an indication for CT scan and possibly laparotomy.
- Patients selected for observation and nonoperative management should not receive analgesics or prophylactic antibiotics because of the risk of masking important signs and symptoms.

Mechanism of Injury

A distinction should be made between low-velocity and high-velocity penetrating abdominal injuries because the severity of the injury, the treatment, and the prognosis are different. High-velocity injuries cause extensive damage by direct laceration, a shock wave effect, and transient cavitation (see Chapter 11, Ballistics). Although rare in the civilian sector, almost all cases with high-velocity injuries require a laparotomy. Low-velocity injuries (knives, most civilian handguns) cause damage only by direct laceration, and often there is no significant intra-abdominal injury requiring surgical repair. Shotgun injuries at close range cause massive tissue destruction. However, at distances longer than about 6 meters, they cause limited tissue damage (Figure 5.37 A,B, Figure 5.38 A–C, Figure 5.39, Figure 5.40 A–C).

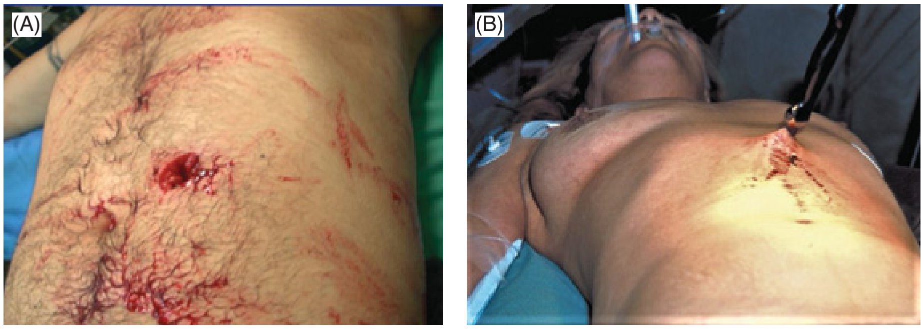


Figure 5.37 A,B Knife wounds to the anterior abdomen require an operation in only 50% of the cases (A). The decision to operate or observe is based on clinical examination and CT scan evaluation. Stab wound to the abdomen with impaled knife. The knife should only be removed in the operating room (B).

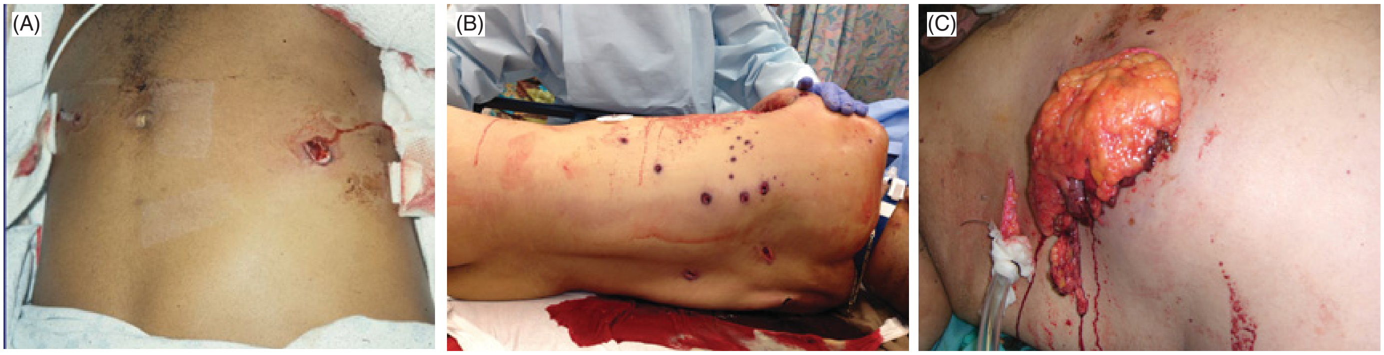


Figure 5.38 A–C Low-velocity gunshot wound (A). About 75% of these wounds have significant injuries requiring surgical repair. The decision to operate or observe is based on clinical examination and CT scan evaluation. Multiple low-velocity gunshot wound of the back (B). Note the limited tissue destruction with these injuries. High-velocity gunshot wounds usually cause extensive tissue destruction (C).

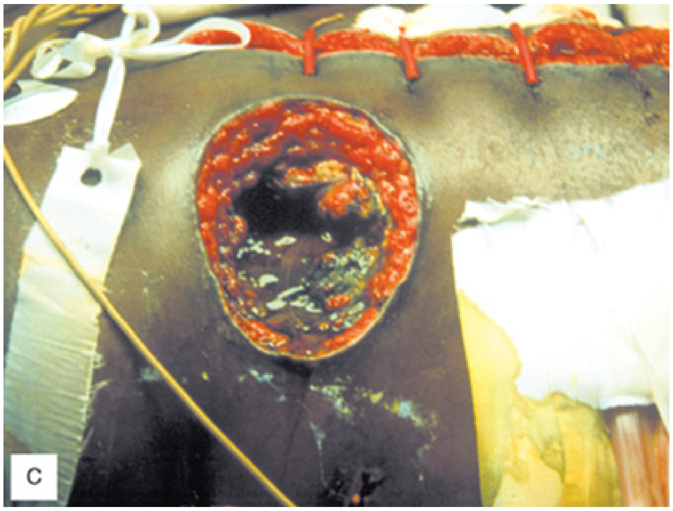


Figure 5.39 Shotgun wound to the abdomen. At close range, they are highly destructive with extensive tissue loss.

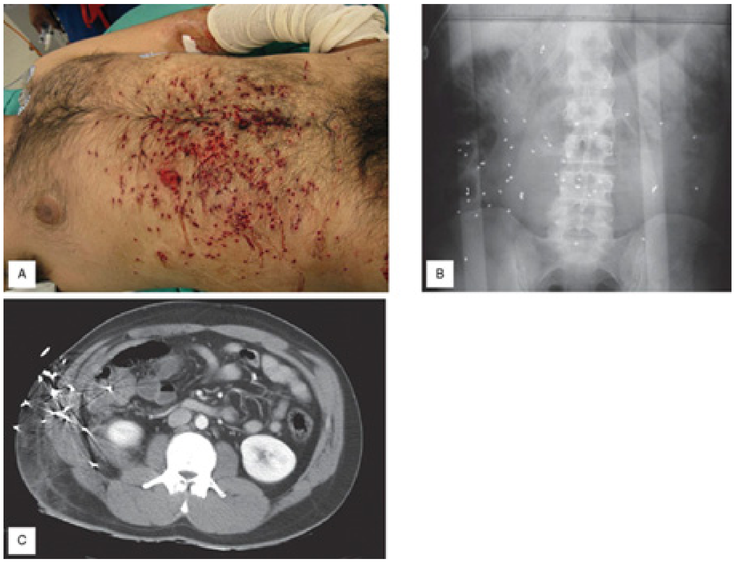


Figure 5.40 A–C Shotgun wound to the abdomen, from about 6 meters distance. From this distance, the ability of the projectiles to penetrate the soft tissues is limited. Note the minor soft tissue damage (A). The plain X-ray shows significant scatter of the pellets (B). The CT scan shows that most of the pellets remained in the soft tissues, outside the peritoneal cavity (C).

Although some centers recommend routine laparotomy for low-velocity injuries, most practice selective nonoperative management. Criteria for nonoperative management are hemodynamic stability and an examinable patient without evidence of peritonitis. These patients are closely monitored with frequent hemodynamic and abdominal examinations and serial white blood cell counts for 24–48 hours.

Omental or bowel evisceration is associated with significant intra-abdominal injuries, requiring surgical repair in approximately 75% of cases (Figure 5.41, Figure 5.42 A,B).

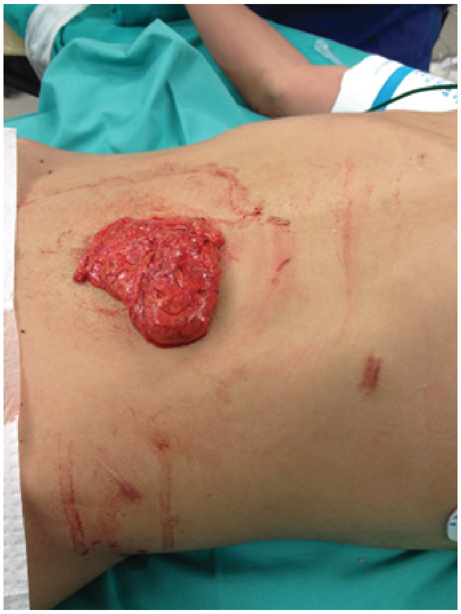


Figure 5.41 Evisceration of omentum following a knife wound to the abdomen. Associated significant intra-abdominal injuries are found in about 75% of these patients.

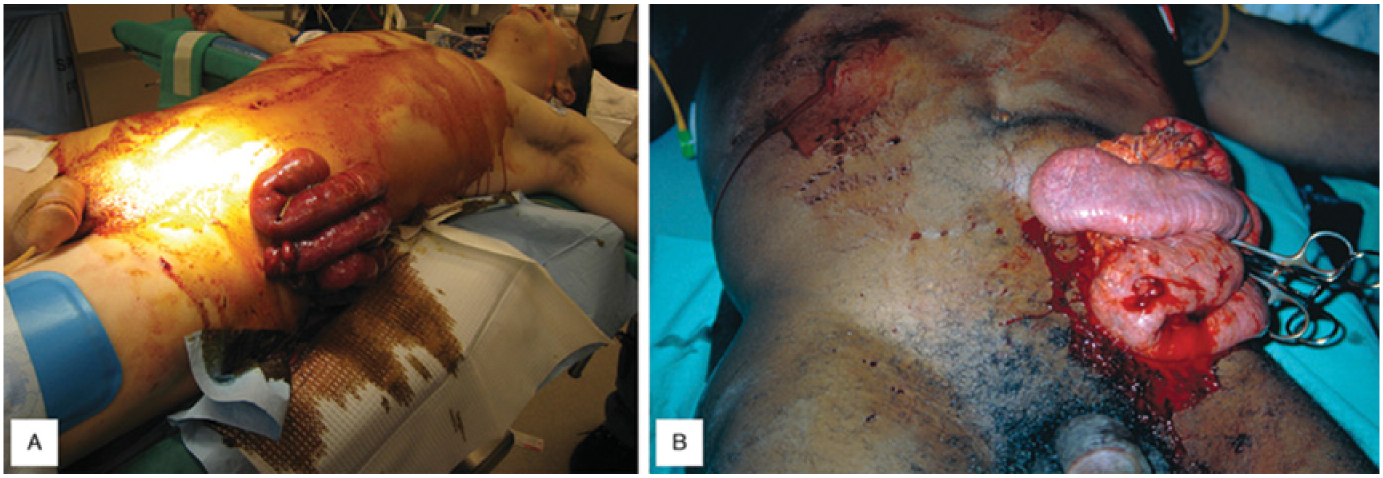


Figure 5.42 A,B Evisceration of bowel following stab wound to the abdomen. If the operating room is not immediately available, an attempt should be made to return the bowel into the peritoneal cavity preoperatively. Patient coughing and straining may aggravate the evisceration.

Investigations

Investigations should be reserved for hemodynamically stable patients. Chest and abdominal X-rays are important in gunshot wounds for localization of any missiles or fragments. Also, they may identify any fractures, especially of the spine (Figure 5.43 A,B). Abdominal X-rays are of limited value in knife injuries and should rarely be performed.

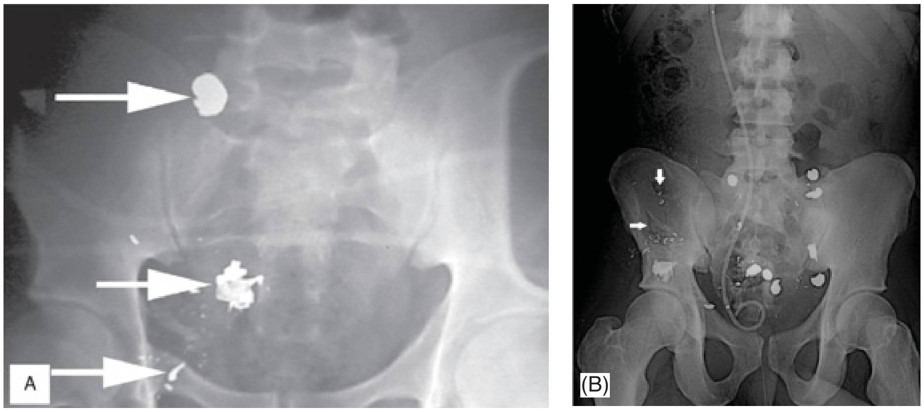


Figure 5.43 A,B Gunshot wound to the abdomen: Plain radiograph showing two missiles and small fragments (A). Multiple gunshot wounds to the abdomen and pelvic fractures (arrows; B).

In hemodynamically stable patients with minimal or no abdominal pain, abdominal CT scan is very helpful in identifying the bullet tract or any solid organ injuries. For solid organ injuries, the CT scan provides information about the injury grade and the presence of active bleeding or false aneurysm, and it is helpful in planning the optimal treatment. In the appropriate setting, many of these solid organ injuries can be managed nonoperatively (Figure 5.44, Figure 5.45 A,B, Figure 5.46 A,B).

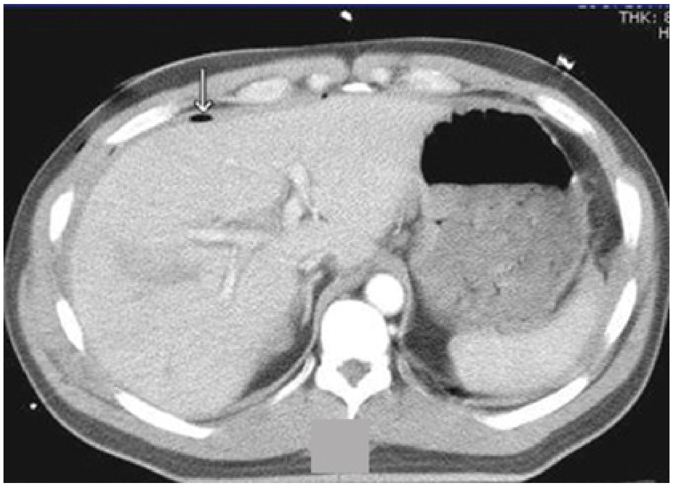


Figure 5.44 Patient with an abdominal gunshot wound. CT scan showing a small amount of free intraperitoneal air (arrow). During operation, a small intestinal perforation was found.

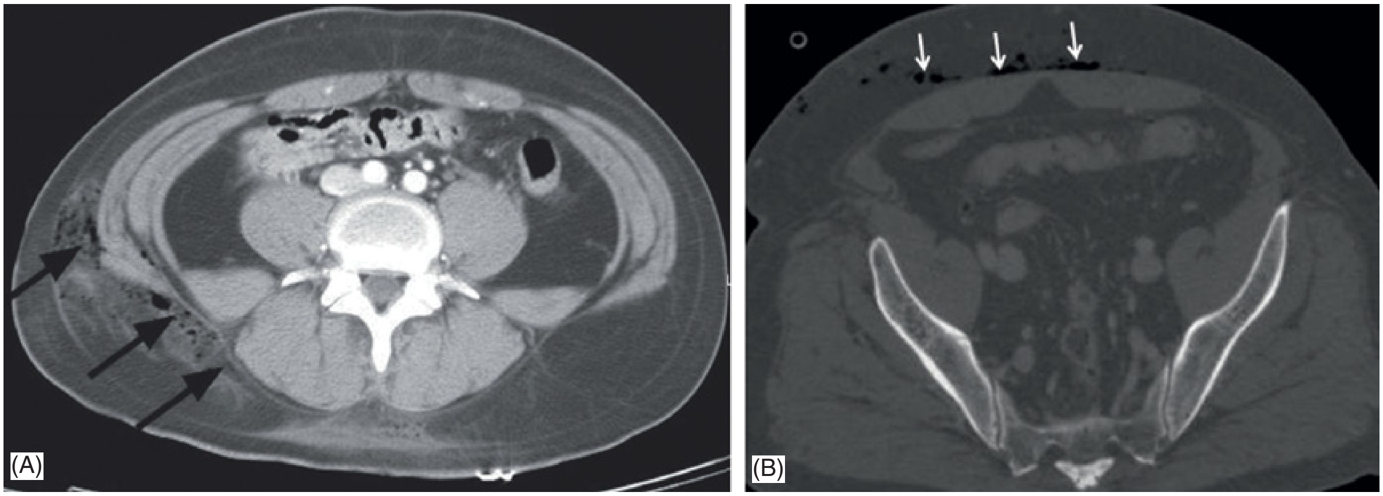


Figure 5.45 A,B CT scans of patients with gunshot wounds to the abdomen. The missile tract is extraperitoneal (arrows; A, B). These patients can be safely managed nonoperatively.

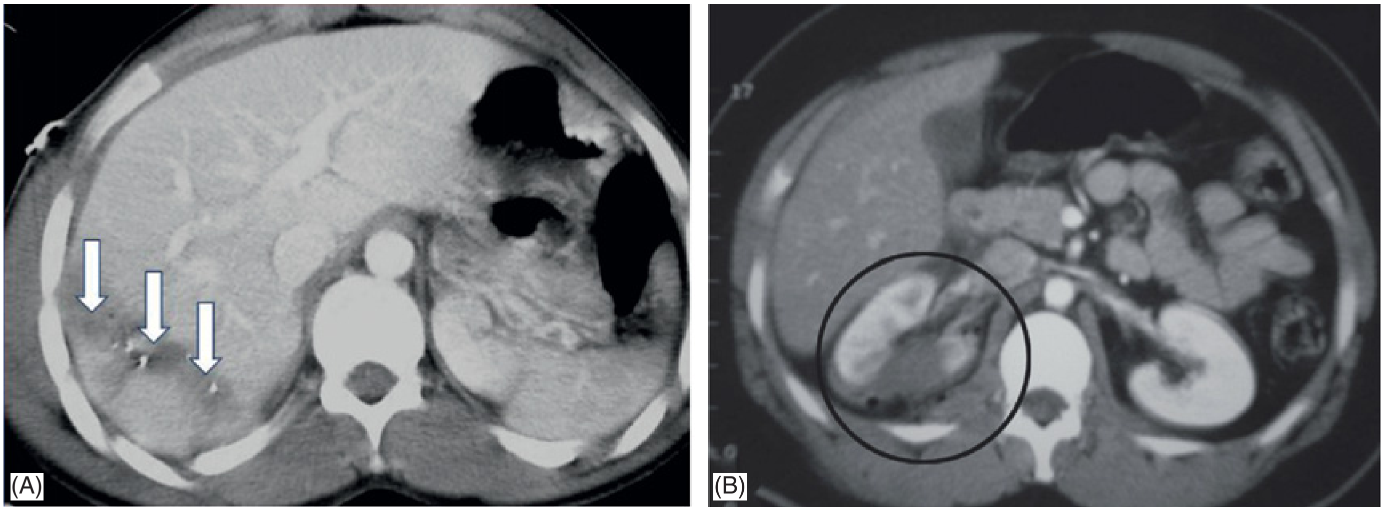


Figure 5.46 A,B Patient with an abdominal gunshot to the right hypochondrium; hemodynamically stable and no signs of peritonitis. CT shows liver injury (arrows) without active bleeding. This patient was successfully managed nonoperatively (A). Patient with a gunshot to the back, hemodynamically stable and no signs of peritonitis. CT shows right kidney injury (circle) without active bleeding. This patient was successfully managed nonoperatively (B).

Laparoscopy is useful in the evaluation of penetrating injuries of the left thoracoabdominal region in hemodynamically stable patients with no signs of peritonitis, to evaluate for diaphragmatic injuries (Figure 5.47). This procedure is discussed extensively in Chapter 4, Thoracic Injury.

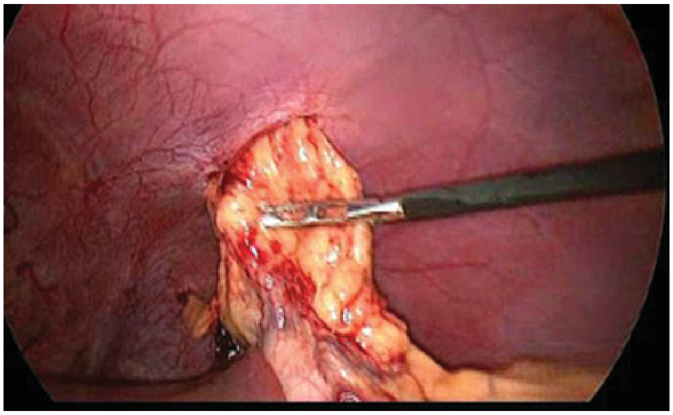


Figure 5.47 Patient with a stab wound to the left thoracoabdominal area and no signs of peritonitis. CT scan was normal. Laparoscopic evaluation showing a diaphragm injury with omental herniation.

Transpelvic Gunshot Injuries

About half of all transpelvic gunshot injuries are associated with significant injuries requiring surgical repair. The selection of patients for operation or observation should be based on clinical examination and appropriate diagnostic tests. The presence of an acute abdomen, hemodynamic instability, rectal bleeding, or gross hematuria is an absolute indication for operation. Injuries to extraperitoneal organs (rectum, urethra) may not give peritoneal signs. Asymptomatic patients should be evaluated by CT scan with gastrografin enema. In selected cases, a rigid sigmoidoscopy may be useful (Figure 5.48 A,B, Figures 5.49 A,B).

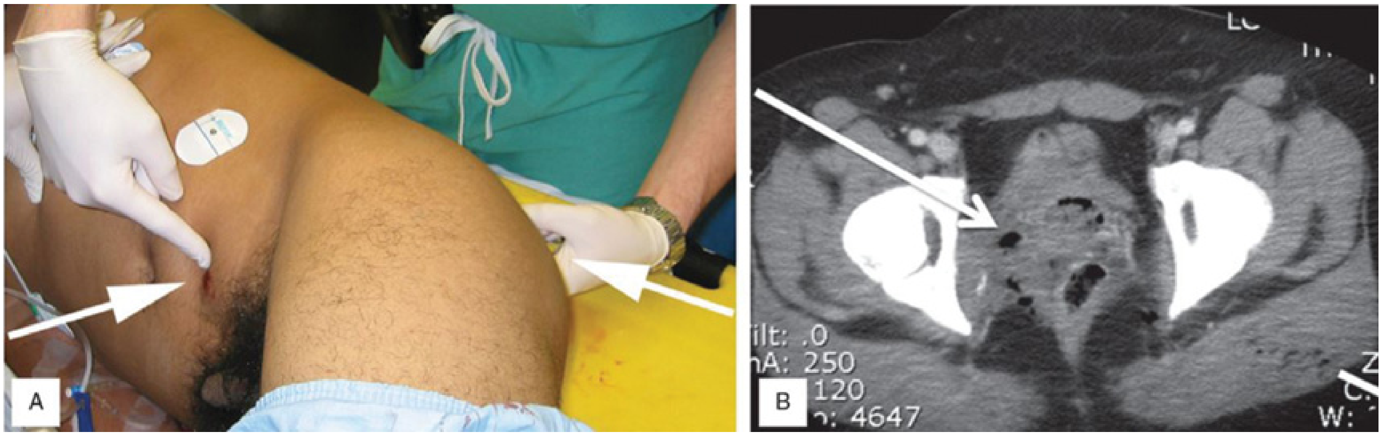
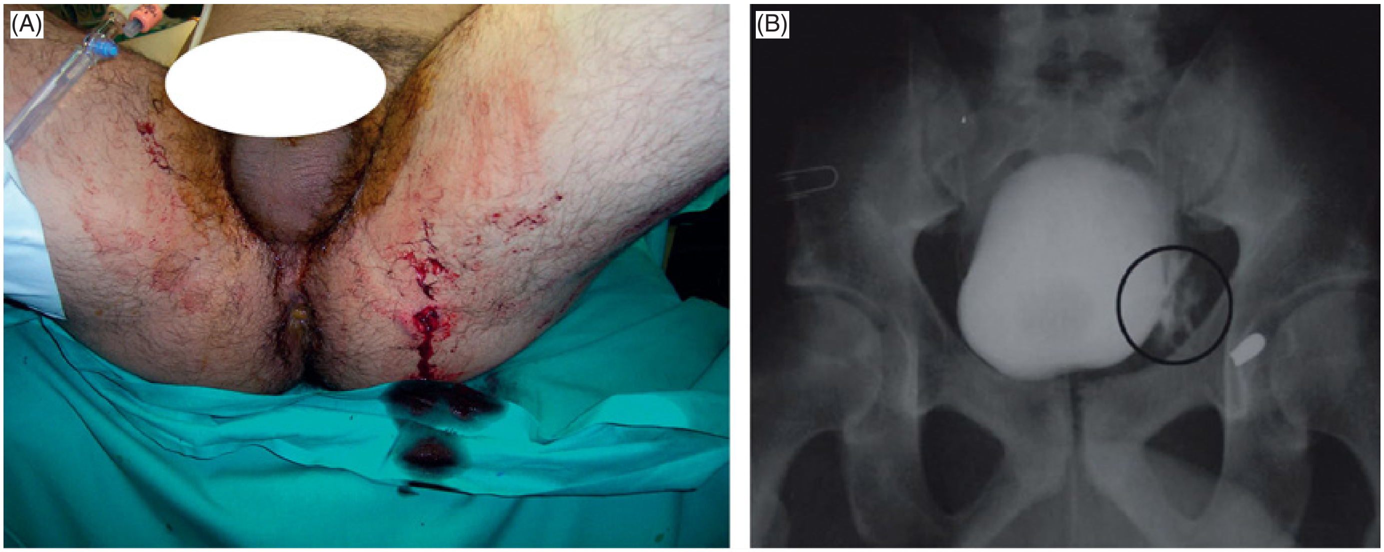


Figure 5.48 A,B Transpelvic gunshot wound (A). CT demonstrating transpelvic trajectory through rectum and extraluminal gas (arrows; B).



Figures 5.49 A,B Transpelvic gunshot wound with gross hematuria: cystogram showing intraperitoneal bladder injury with contrast extravasation (circle).

Penetrating Injuries to the Liver

About 30% of all knife wounds to the liver may be managed nonoperatively. Although gunshot wounds to the liver were traditionally managed with mandatory laparotomy, selective nonoperative management of these injuries is safe and has become widely accepted. Hemodynamically stable patients without peritonitis are candidates for nonoperative management. A CT scan with intravenous contrast should always be performed to assess the extent of the injury and identify any evidence of active bleeding or false aneurysms, which may benefit from angiographic embolization. Hemodynamic instability or the presence of peritonitis are indications for laparotomy (Figure 5.50 A–E, Figure 5.51, Figures 5.52 A,B, Figures 5.53 A,B).

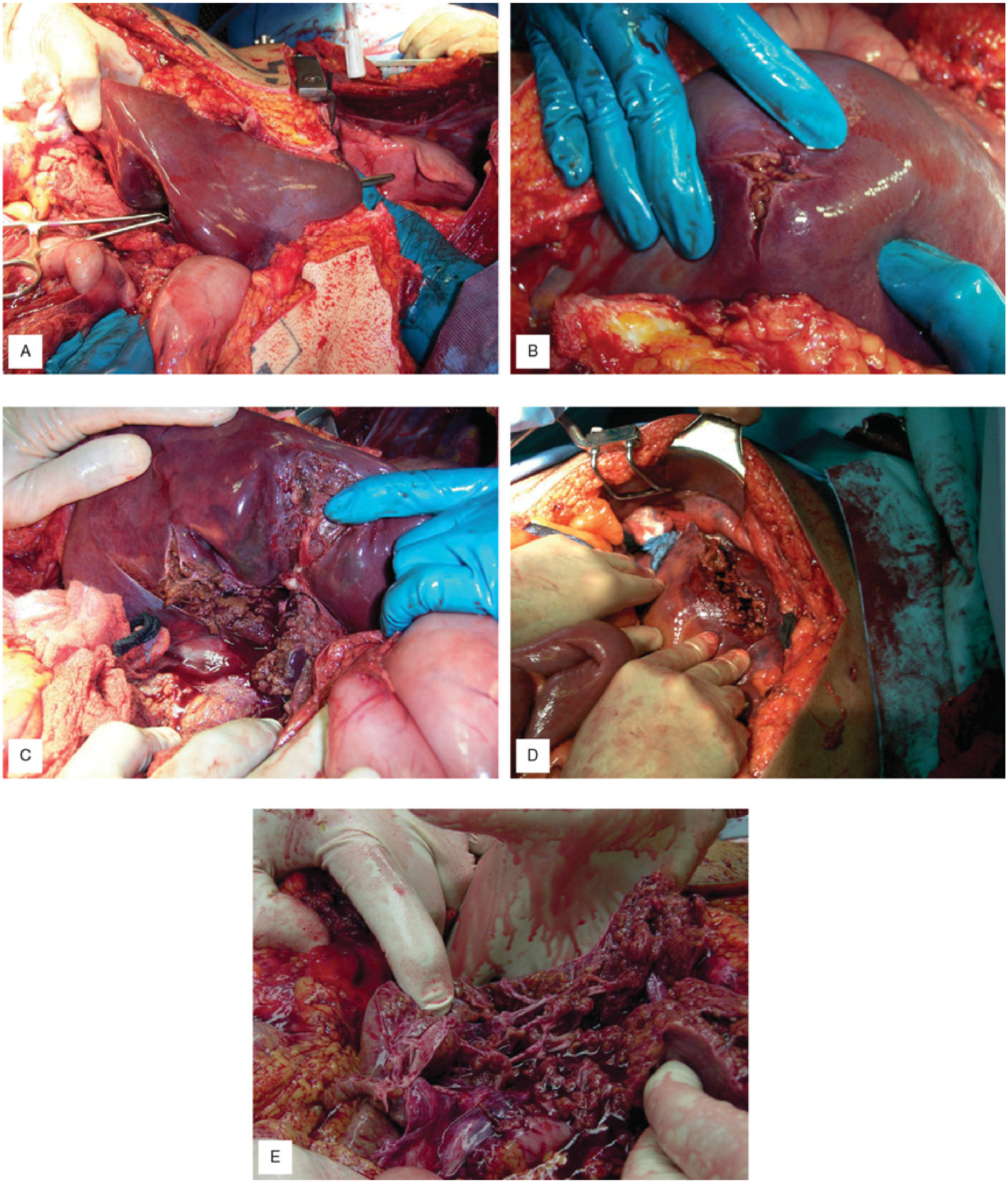


Figure 5.50 A–E Low-velocity gunshot wounds to the liver (A–D). High-velocity gunshot wound to the liver (E).

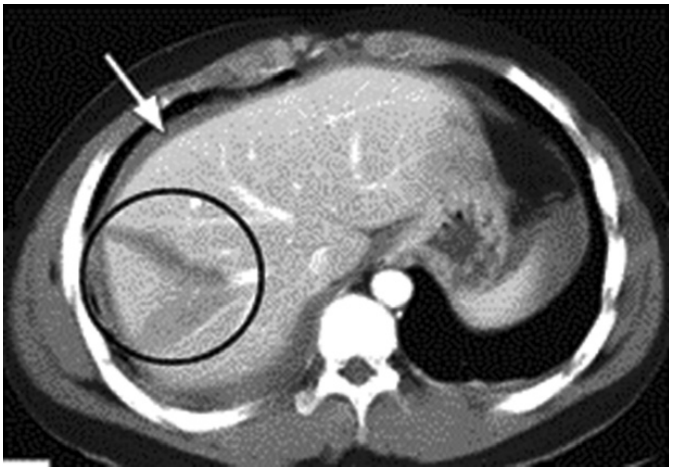
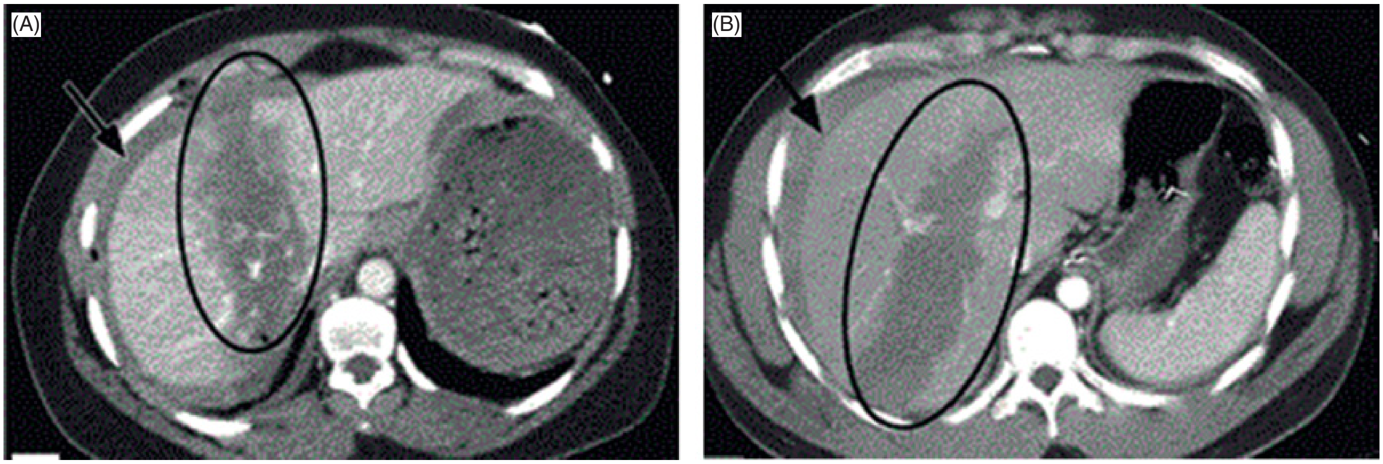
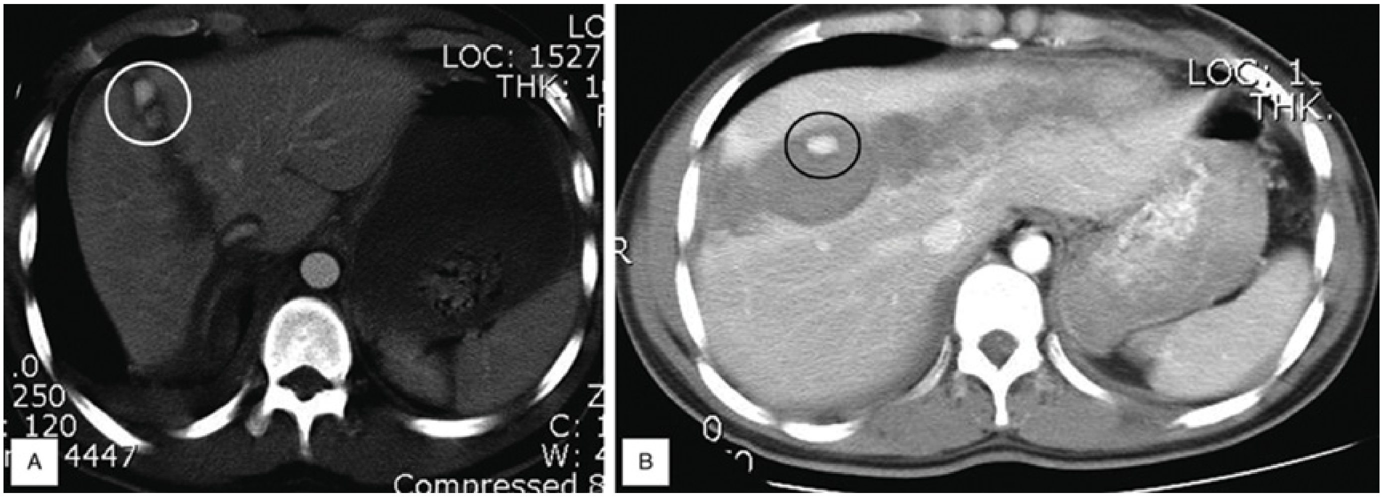


Figure 5.51 Many penetrating liver injuries can safely be managed nonoperatively, provided the patient is hemodynamically stable stab wound to the liver (circle), with a small amount of perihepatic blood (arrow), and has no peritonitis. A contrast CT scan should always be performed: CT scan of to the liver successfully managed nonoperatively.

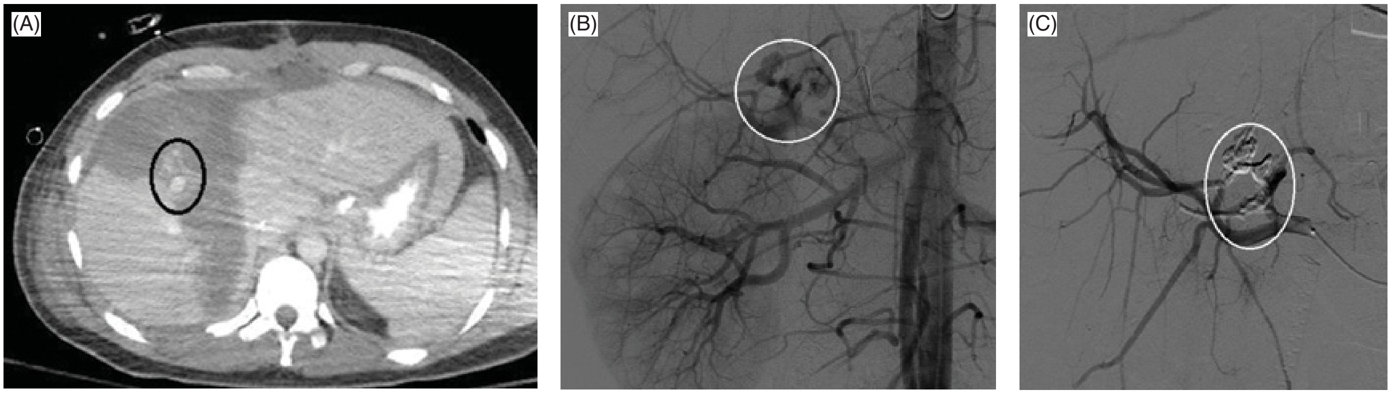


Figures 5.52 A,B CT scans of patients with abdominal gunshot wounds, hemodynamically stable and no signs of peritonitis, showing high grade liver injuries. These patients were successfully managed nonoperatively.



Figures 5.53 A,B CT scan of a patient with a gunshot wound shows a severe liver injury with a pseudoaneurysm (circle). Angiography confirmed the aneurysm, and successful embolization was performed. The patient was managed nonoperatively. CT scan of a patient with a transhepatic gunshot wound, shows a pseudoaneurysm, which was successfully managed with angioembolization (B).

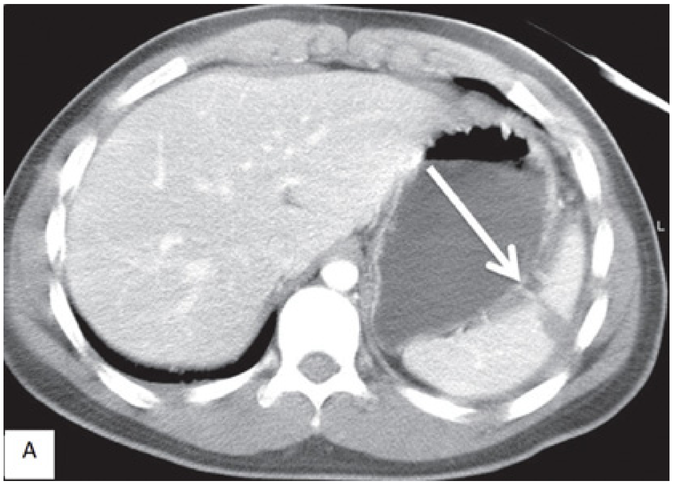
Complications of penetrating liver injuries include bleeding, false aneurysm, arteriovenous fistula, hemobilia, biloma, biliary leaks, and liver abscess. Most of these complications can be managed successfully with angiographic embolization, percutaneous drainage, or ERCP guided stent placement (Figures 5.54 A–C).



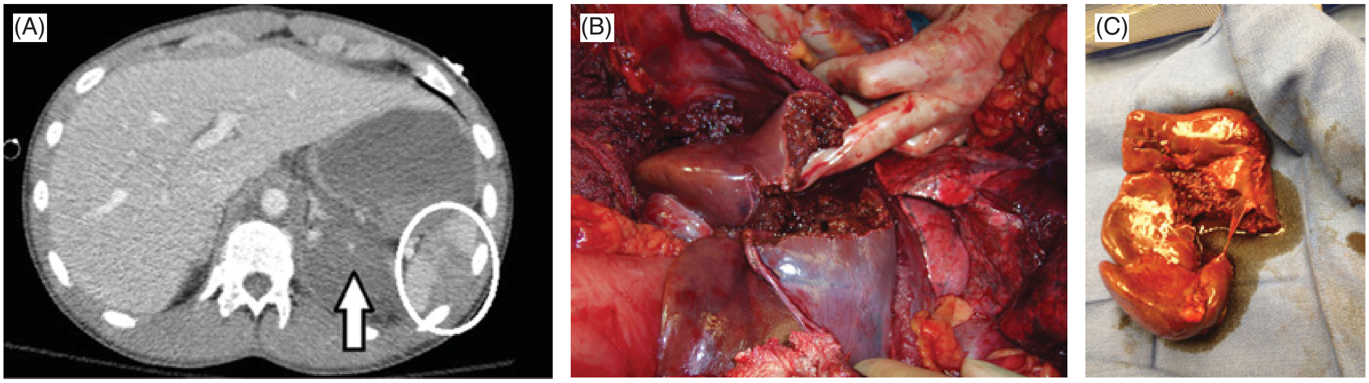
Figures 5.54 A–C Gunshot wound with a high-grade liver injury. CT scan showing a false aneurysm and arteriovenous fistula (circle; A). Angiography confirms the lesions (circle; B). Successful angioembolization (circle; C).

Penetrating Splenic Injuries

Some penetrating injuries to the spleen can be safely managed nonoperatively, provided the patient is hemodynamically stable, is evaluable, and does not have peritonitis. However, in the majority of cases, there are associated intra-abdominal injuries or significant bleeding, and the patient needs an emergency laparotomy. Investigations should be reserved for stable patients and should include abdominal CT scanning with intravenous contrast. Laparoscopy should be considered in all asymptomatic patients with left thoracoabdominal injuries to evaluate for diaphragmatic injury (Figures 5.55, Figures 5.56 A–C).



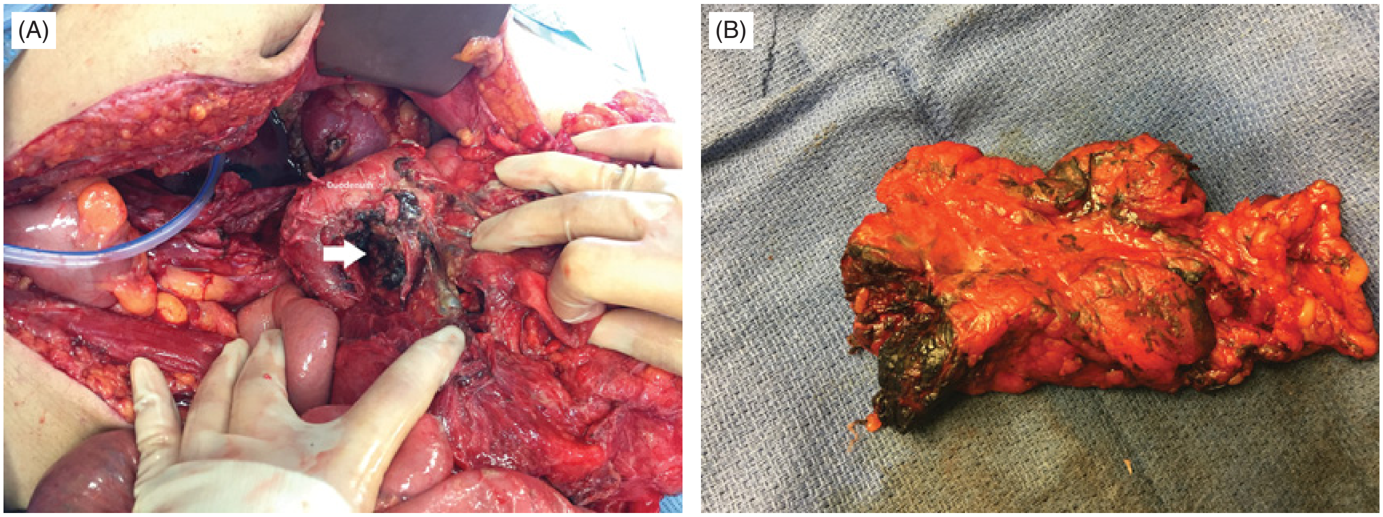
Figures 5.55 Abdominal gunshot wound with CT scan showing a low grade splenic injury (arrow). The patient was successfully managed nonoperatively.



Figures 5.56 A–C Abdominal gunshot wound with CT showing a high-grade splenic injury (circle) and a large perisplenic hematoma (arrow; A). Intraoperative appearance of the splenic injury (B). Photograph of the removed spleen (C).

Penetrating Pancreatic Injuries

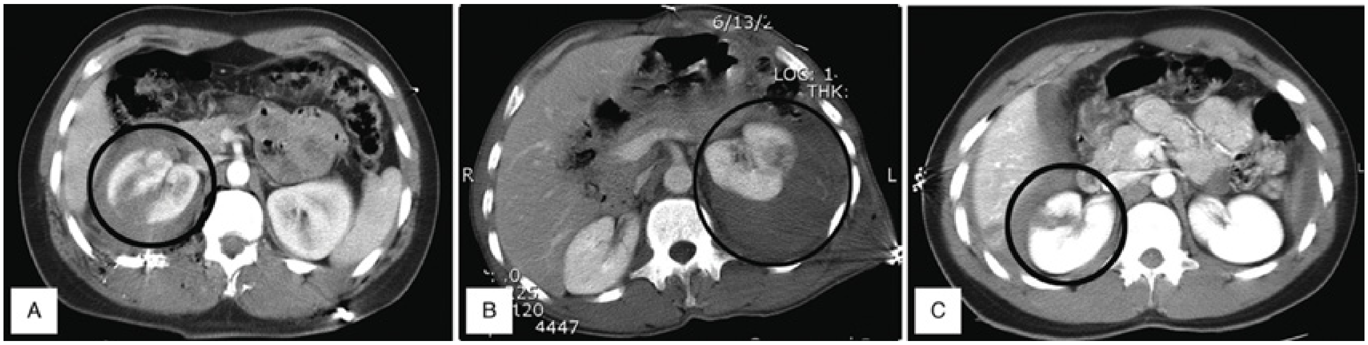
Almost all penetrating pancreatic injuries require operation because of the severity of the injury and the presence of other associated injuries. The management of the pancreatic injury may vary from simple drainage to distal pancreatectomy or pancreatoduodenectomy (Figures 5.57 A,B). Complications include pancreatitis, pancreatic fistula, pancreatic ascites, pseudocyst, and abscess.



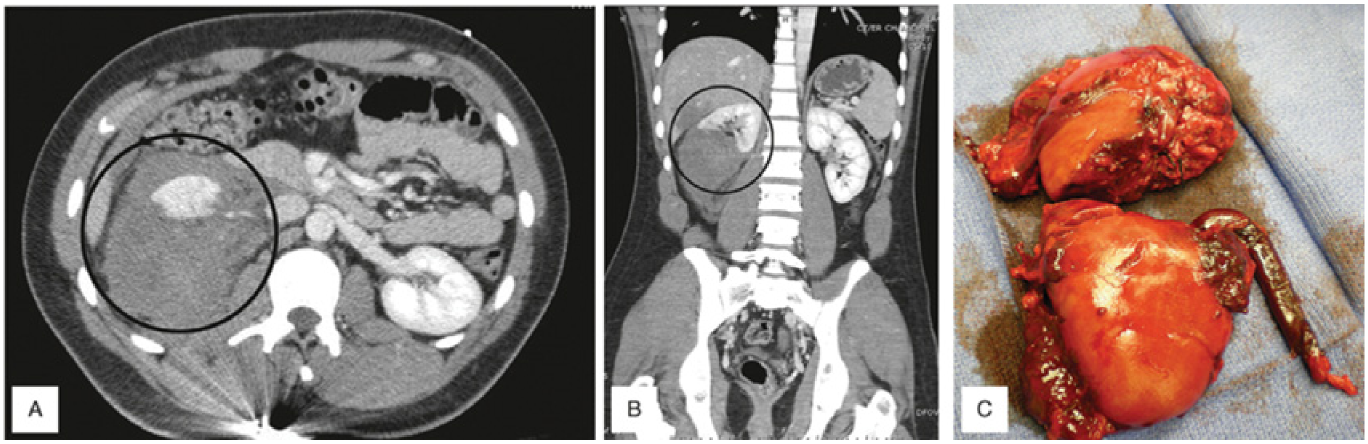
Figures 5.57 A,B Intraoperative appearance of a gunshot wound to the head of the pancreas (arrow; A). Distal pancreatectomy specimen for a gunshot wound to the body of the pancreas (B).

Penetrating Renal Injuries

Many isolated penetrating kidney injuries can be managed nonoperatively, provided the patient is hemodynamically stable and has no signs of peritonitis. A CT scan with intravenous contrast should always be performed to assess the extent of parenchymal injury and the presence of pelvicalyceal system leak or vascular lesions such as false aneurysm or arteriovenous fistula (Figures 5.58 A–C, Figures 5.59 A–C).



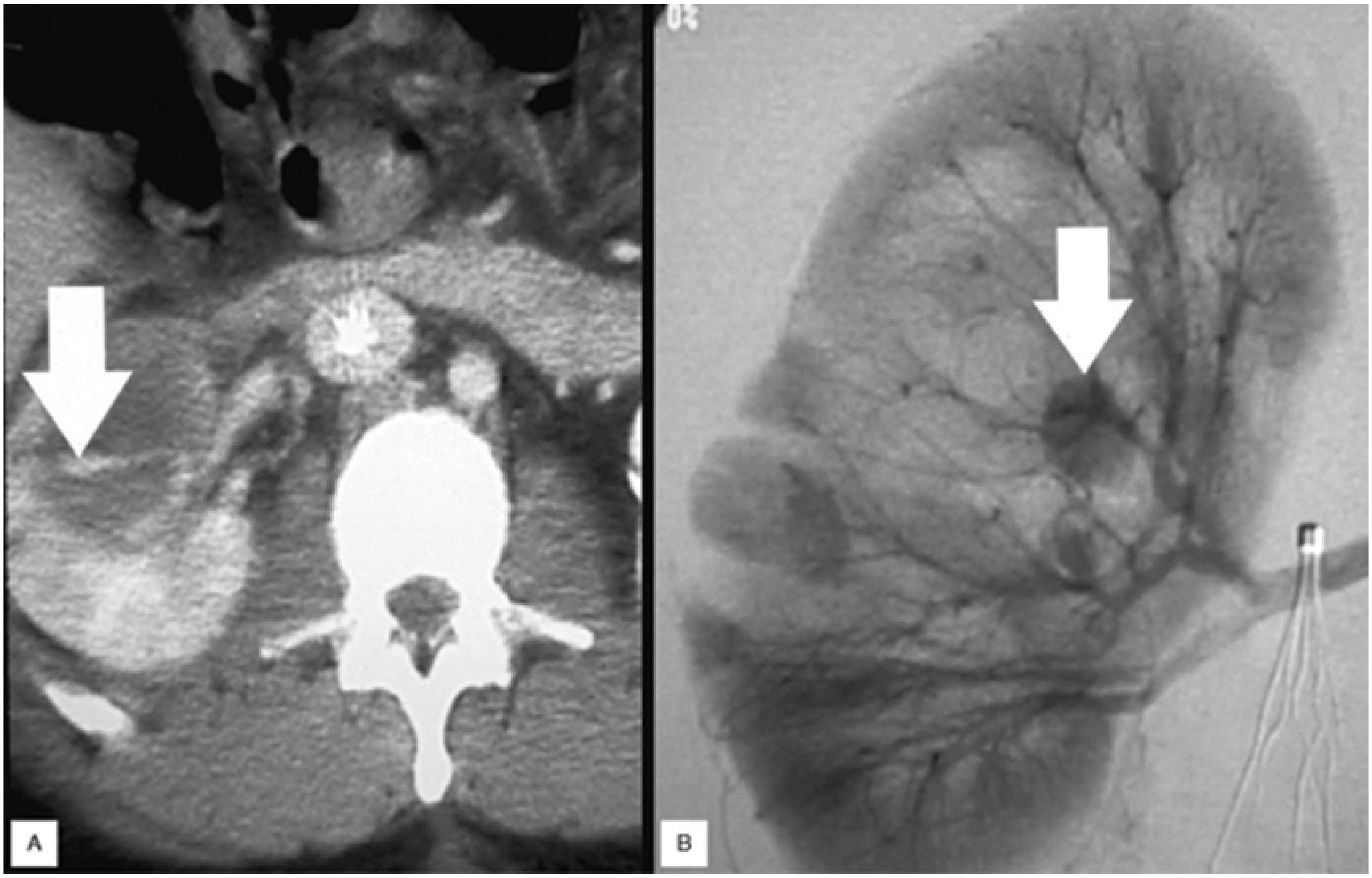
Figures 5.58 A–C CT scans demonstrating penetrating injuries to the kidney managed nonoperatively.



Figures 5.59 A–C Gunshot injury to kidney, CT scan showing severe injury, and a large perinephric hematoma (circle; A, B). A nephrectomy was performed. Note the complete transection of the kidney (C).

Angiography with possible embolization should be performed in cases with persistent gross hematuria or suspected aneurysm or arteriovenous fistula on CT scan.

Complications associated with kidney preservation include urinoma, false aneurysm, arteriovenous fistula, abscess, and late hypertension. Most of these complications can be managed with interventional radiology (Figures 5.60 A,B).



Figures 5.60 A,B Delayed presentation of a pseudoaneurysm (arrows) following a gunshot wound to the kidney.

Penetrating Colorectal Injuries

Almost all intraperitoneal colorectal injuries give early signs of peritonitis, and they are usually easy to diagnose. However, small retroperitoneal colonic or extraperitoneal rectal injuries may not give any early clinical signs. Rectal examination may show blood in the stool. Abdominal CT scan with IV and rectal contrast are very reliable in the diagnosis of these injuries. A carefully performed sigmoidoscopy may show blood in the rectum or even the actual perforation.

Early surgical intervention is important to reduce the risk of septic complications. All colon injuries require an emergency operation (Figure 5.61 A,B).

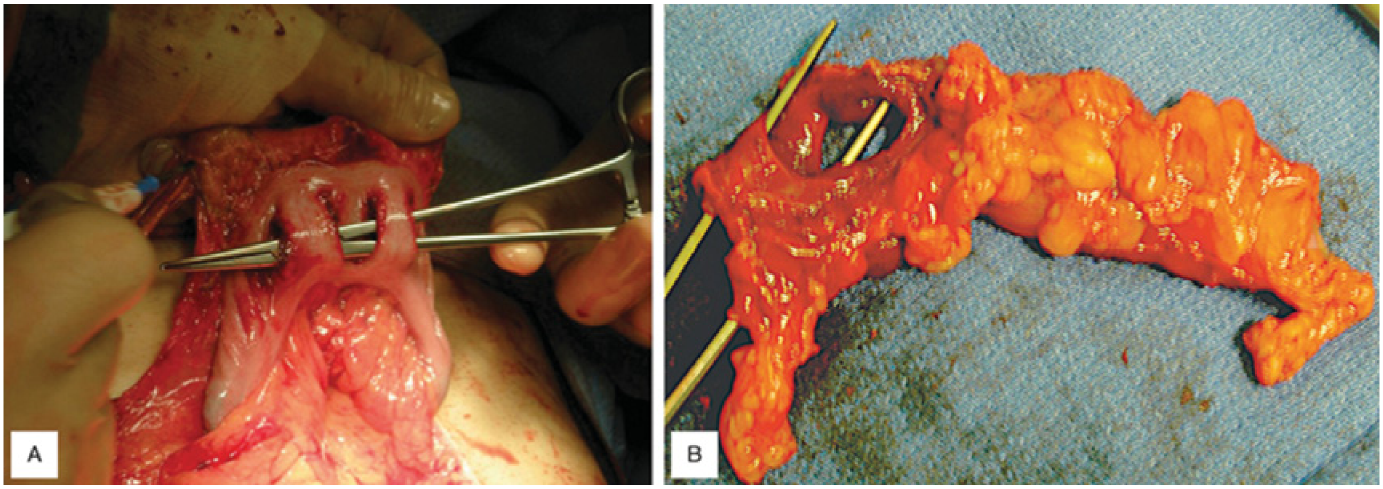


Figure 5.61 A,B Gunshot injuries with destructive trauma to the colon requiring resection. These injuries are associated with a very high incidence of septic complications.

Abdominal Vascular Injuries

Most patients with penetrating abdominal vascular injuries present in shock, although in some cases retroperitoneal containment may prevent rapid exsanguination and early shock. Peritonitis due to associated hollow viscus perforation is a common finding. The diagnosis of vascular injury should be suspected in the presence of hemodynamic instability or a rapidly distending abdomen (Figure 5.62 A,B). A FAST exam

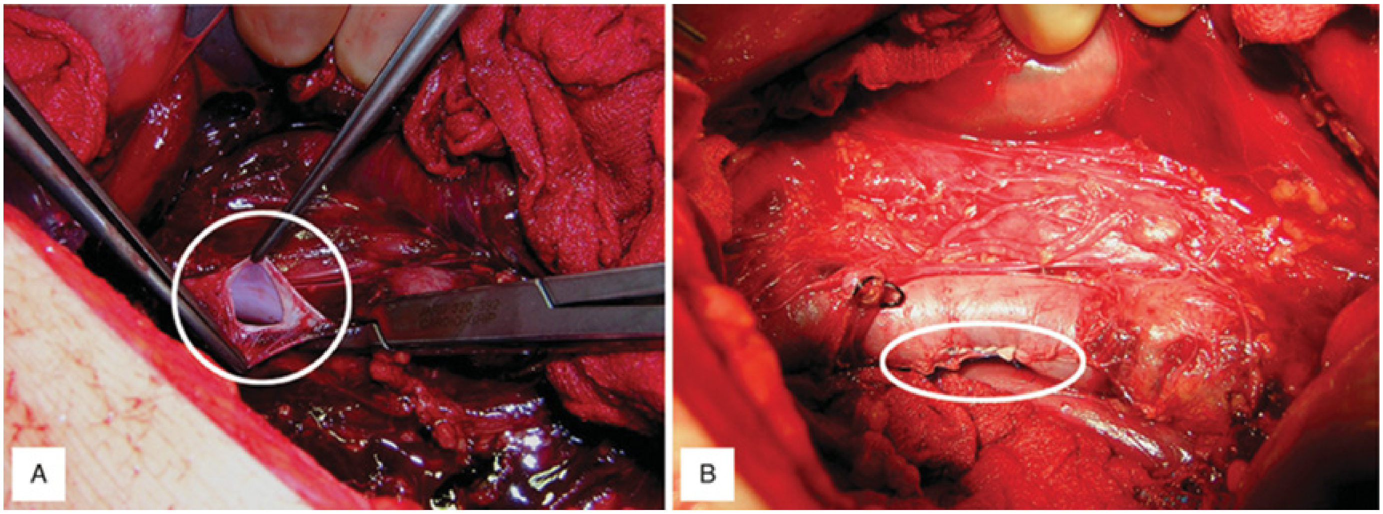


Figure 5.62 A,B Stab wound to the infrarenal inferior vena cava: before (A) and after (B) primary repair.

usually identifies intraperitoneal bleeding, although it often misses retroperitoneal bleeding. CT angiography is very valuable in diagnosing contained vascular injuries, pseudoaneurysms and arteriovenous fistulas (Figure 5.63 A,B).

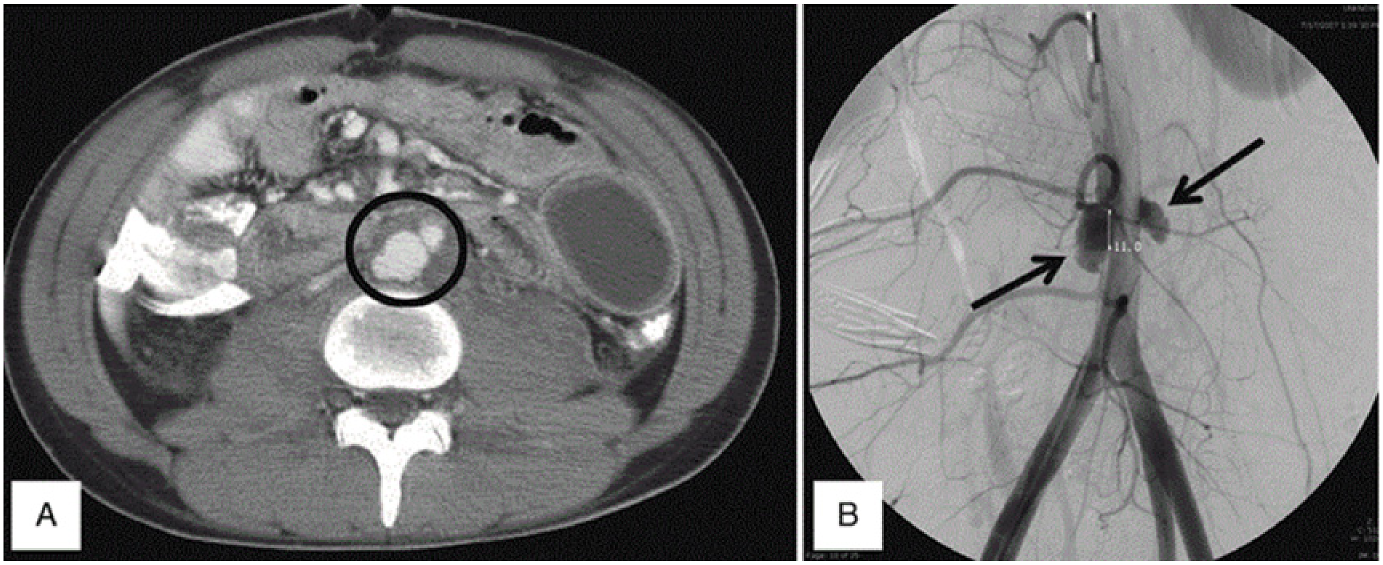


Figure 5.63 A,B Gunshot wound to the abdominal aorta with leak and pseudoaneurysm below the renal arteries. CT scan (A); formal angiography (B).

Chapter

6

Musculoskeletal Injury

Carl R. Chudnofsky and Edward J. Newton

Introduction

Orthopedic injuries are found in approximately 85% of blunt trauma victims; thus knowledge of their evaluation and treatment is important. Some of these injuries are also acutely life- or limb-threatening and need to be treated in an expedited fashion. Despite the importance of early treatment, the standard primary survey promulgated by the ATLS course is necessary to detect other injuries that have a higher priority. During the primary survey, the only attention to musculoskeletal injury is acute hemorrhage control with direct pressure.

Clinical Examination

The physical exam is an integral component of detecting acute orthopedic injuries. Examine the overlying skin for contusions and lacerations. Explore all lacerations for neurovascular injury, tendon injury, foreign bodies, and proximity to fracture sites. Cool, pale skin may indicate acute vascular insufficiency. Check capillary refill and peripheral pulses of injured extremities and compare them to the unaffected limb whenever possible. In some cases, doppler ultrasound may be required to detect poor pulses. Palpate muscle compartments for firmness that may indicate an acute compartment syndrome. General range of motion and areas of tenderness help guide necessary radiographs. Careful peripheral nerve exam is also important, as nerve injury may be part of the injury complex.

Investigations

1. Plain X-rays are indicated for most orthopedic injuries. Fractures are usually evident on plain radiographs, but occasionally the fracture is occult, requiring further imaging (i.e., CT) that is generally guided by the clinical exam. Obtain X-rays of the affected bone in at least two perpendicular planes and be sure that the films provide a full view of the involved bone, including the joints above and below the suspected injury. Depending on the spectrum of injuries, full radiographic evaluation may need to be delayed in order to treat life-threatening injuries.
2. CT scan is useful in evaluating patients with continued pain and normal X-rays, such as in acute hip injuries. CT scans also provide much more detail of an identified injury and allow 3-D reconstruction.
3. MRI is rarely needed to acutely evaluate musculoskeletal injuries. It is useful in detecting occult fractures, as in hip injuries, and is also useful in delineating ligamentous and cartilaginous injuries, such as may be seen with acute knee trauma. It also has a prominent role in the evaluation of spinal injuries.
4. Bone scanning at 72 hours is occasionally used to follow-up patients who may have occult fractures of the scaphoid.
5. Doppler ultrasound or CTA are used to evaluate patients with possible vascular injury.
6. Intracompartment pressure can easily be measured with portable equipment and can help guide the management of patients with possible compartment syndrome (see Chapter 10, Extremity Compartment Syndrome).

General Management

Life-threatening injuries receive priority, and thus many orthopedic injuries receive more extensive evaluation and treatment after initial stabilization and treatment of more critical injuries. Some orthopedic injuries, however, may be life-threatening and require similar prioritization. Major pelvic fractures are associated with significant retroperitoneal hemorrhage, which is often difficult to control. Liberal blood transfusions, expedited stabilization of the fracture, and emergency angiography with embolization may be necessary to restore hemodynamic stability. Major arterial injury with exsanguination may occur with penetrating injury or by blunt force with fracture or dislocation-induced vessel laceration. Depending on the involved vessel and the clinical status of the patient, emergency operative therapy may be necessary to control bleeding. Significant soft tissue destruction may cause rhabdomyolysis that can lead to acute renal failure if not promptly managed with vigorous intravenous hydration, diuretics, and alkalinization of the urine.

Open fractures and open joints are limb-threatening and need irrigation, tetanus immunization, and parenteral antibiotics. Formal operative debridement is done on an emergent basis. Traumatic amputations will need to be considered for emergency reimplantation, and the amputated part appropriately cared for. Compartment syndrome may develop over hours, and thus high-risk injuries need serial physical examinations and compartment pressure monitoring. Dislocations need prompt reduction, often with deep sedation. Check the neurovascular status of the involved limb before and after the reduction. Closed fractures need at least gross alignment with splinting in the emergency department to decrease bleeding and pain, and prevent further displacement and injury of the adjacent neurovascular structures. Definitive closed or open reduction can be completed once the patient has been stabilized from other injuries.

Open Fractures

Open fractures are true orthopedic emergencies. They are defined as fractures in contact with the outside environment and thus require a break in the skin overlying the fracture site. The skin break may be large and obvious or small and obscure (e.g., puncture wound), and determining whether or not a fracture is open can sometimes be difficult (Figure 6.2 A–C).

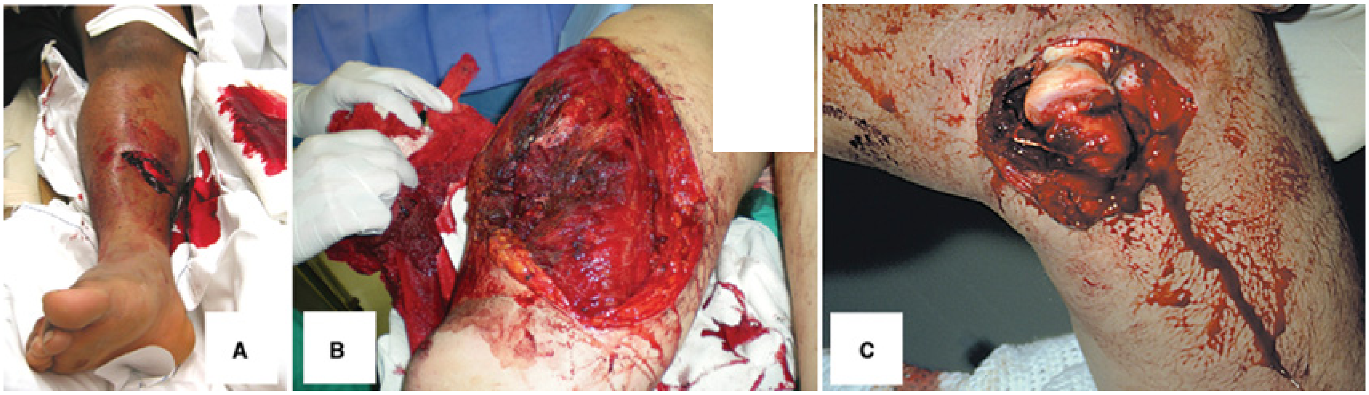


Figure 6.2 A–C Open fracture of mid-tibia (A), elbow (B), and knee (C).

Osteomyelitis, often due to staphylococcus, is a concerning complication of open fractures. Thus all patients with open fractures should receive antibiotic therapy at minimum, active against this organism. Emergency therapy also includes covering the wound with saline moistened sterile dressings, tetanus immunization (if required), and pain management. All open fractures of large bones require early operative irrigation and debridement, while mangled extremities may require more complex emergent operation or amputation.

Mangled Extremity

Mangled extremities are commonly the result of severe crush trauma, high-velocity missiles, or shotgun injuries. There is a combination of orthopedic trauma, extensive soft tissue damage, and injury to the neurovascular structures. The most immediate priority is hemorrhage control, often by the use of tourniquets in the appropriate cases. The initial clinical evaluation should include assessment of the extent of skeletal and soft tissue injury, the presence of peripheral pulses and skin perfusion, and motor and sensory function. Patients with obvious nonsalvageable limbs should be transferred to the operating room for bleeding control and amputation. Investigations should be reserved only for cases with possibly salvageable limbs. In these cases, X-rays should be obtained to determine the extent of the fractures. Color flow doppler studies, CTA, or conventional angiography may be necessary to assess the vascular structures and plan any vascular reconstruction.

The severity of the mangled extremity and the prediction of the need for amputation are commonly assessed with the Mangled Extremity Severity Score (MESS), which takes into account the extent of the skeletal/soft tissue injury, the presence and duration of limb ischemia, the presence of shock on admission, and the age of the patient. High scores (e.g., >7) are predictive of the need for amputation. Although this scoring system is a useful tool, it has significant limitations and should not be the sole criterion in determining the need for amputation or salvage operations (Figure 6.3 A–E).

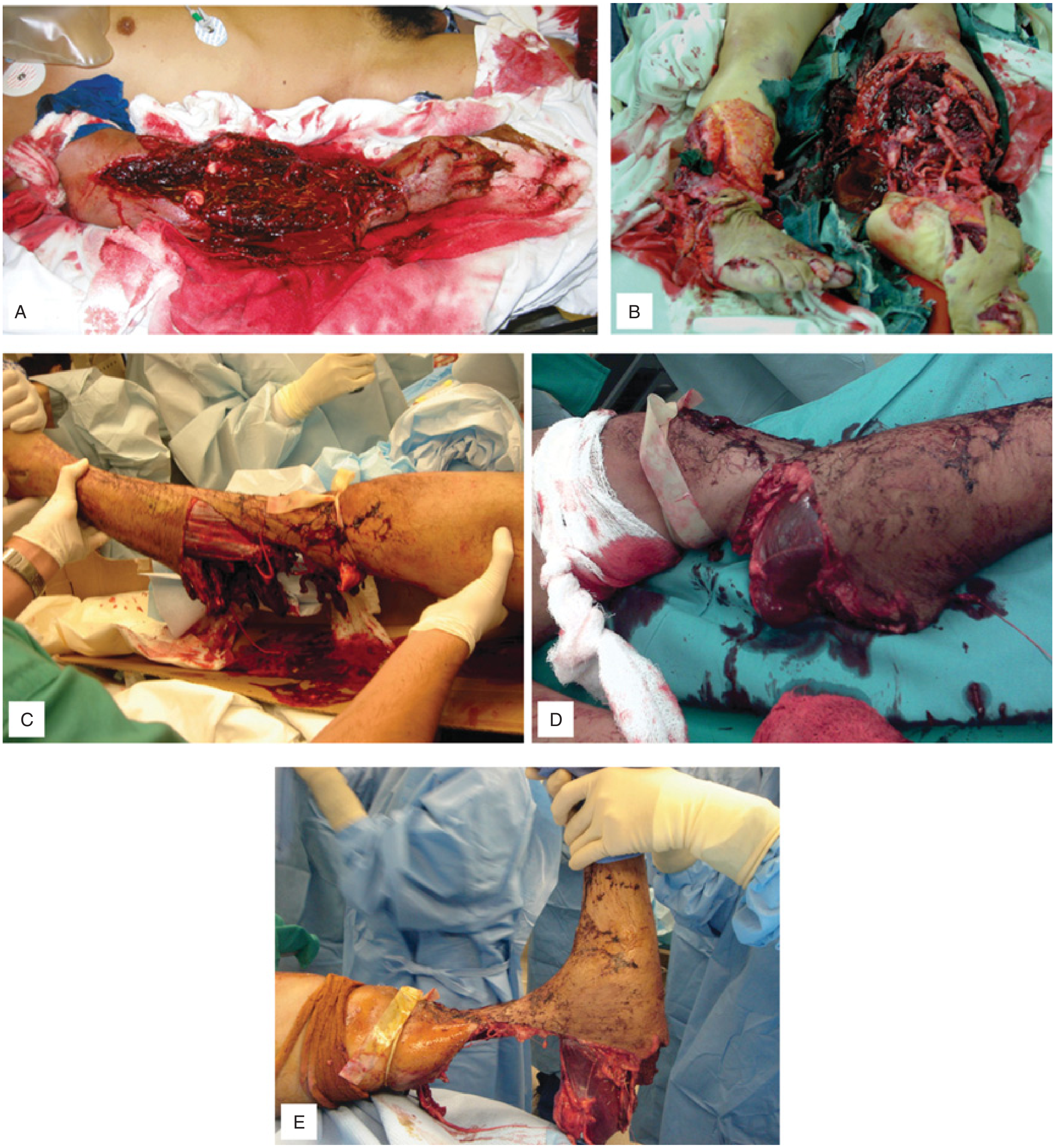


Figure 6.3 A–E Mangled right arm with severe crush injury. This patient accidentally placed his arm into an industrial mixer. Amputation was required (A). Mangled lower legs bilaterally, following a train accident. The patient required bilateral amputations (B). Mangled leg following a motorcycle accident. There is extensive soft tissue loss with neurovascular injury. The patient required amputation (C). Mangled lower leg with fairly limited crushing and loss of skin and muscle. The popliteal vessels were transected. Note the tourniquet above the knee, which was placed to control severe bleeding. The patient underwent successful reconstruction (D). Near-complete amputation of the leg following a motorcycle accident. There is only a bridge of skin holding the leg in one piece (E).

Open Joint Injury

Open joint injuries are serious orthopedic emergencies, with septic arthritis and osteomyelitis being common complications. Detection may be obvious on physical exam or findings may be subtle, requiring adjunctive testing. Any deep wound in proximity to a joint should be considered intra-articular until proven otherwise (Figure 6.4 A–D).

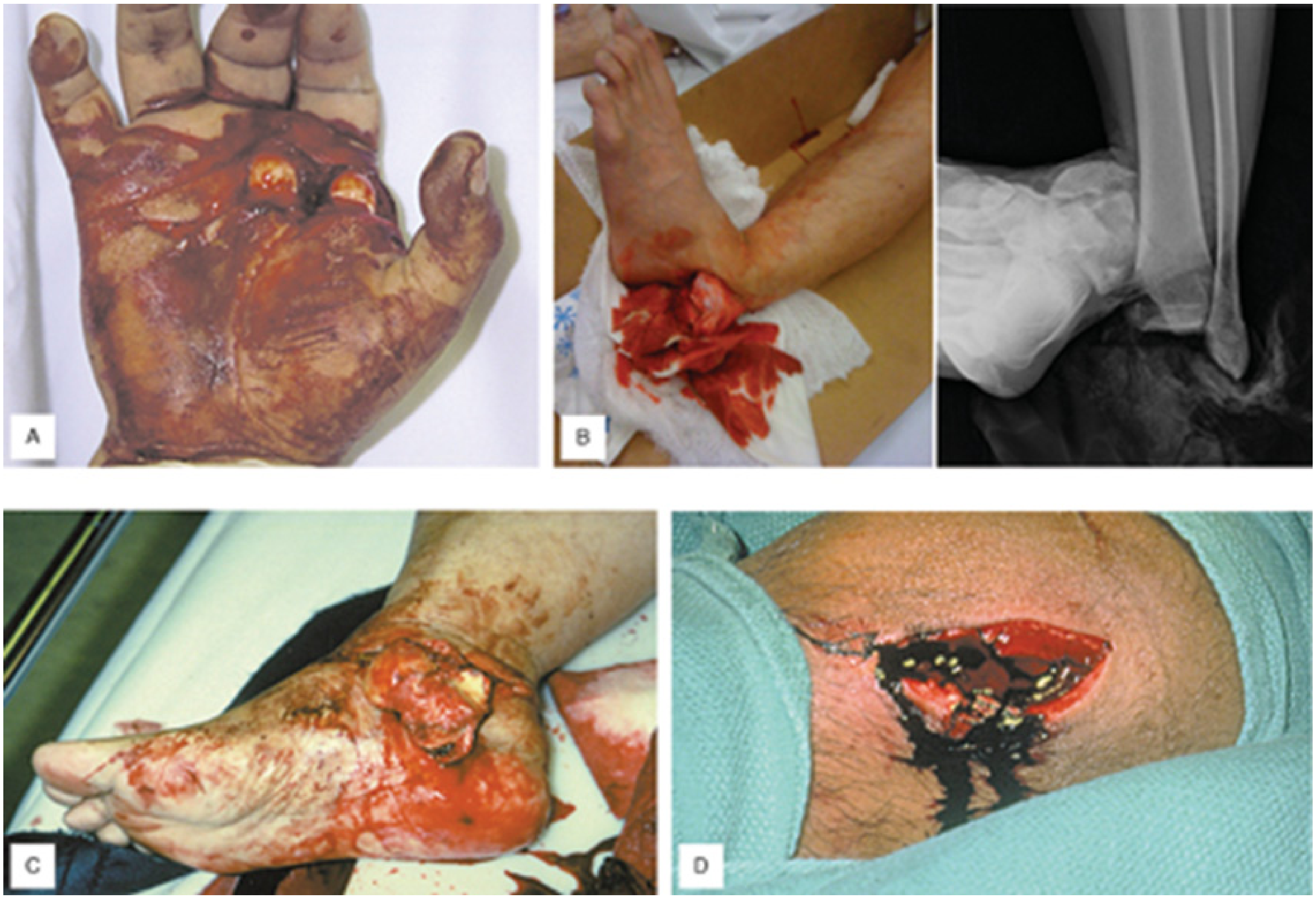


Figure 6.4 A–D Open volar dislocation of the metacarpal joint (A). Photograph (left) and radiograph (right) of an open joint and fracture of the ankle (B). Open joint and fracture of the ankle following a motorcycle accident (C). Photograph of a methylene blue arthrogram of the knee with leakage through the proximal wound signifying an open joint (D).

Plain X-ray after open joint injury can show an associated fracture, air, or a foreign body within the joint, but also may be normal. Careful exploration under sterile conditions may reveal a wound track directly penetrating the joint capsule. In questionable cases, a saline or methylene blue arthrogram may provide the answer by revealing dye leakage through the wound site. Emergency therapy includes broad spectrum parenteral antibiotics, tetanus immunization (if needed), and analgesia. All major open joints require formal exploration and irrigation in the operating suite.

Epiphyseal Injuries

In a growing child, the epiphyseal plate is a weak cartilaginous structure and is predisposed to injury. Injuries most often occur in the zone of hypertrophic cartilage cells, while the germinal cells are usually undamaged, thus, growth is often not affected (Figure 6.5 A-C).

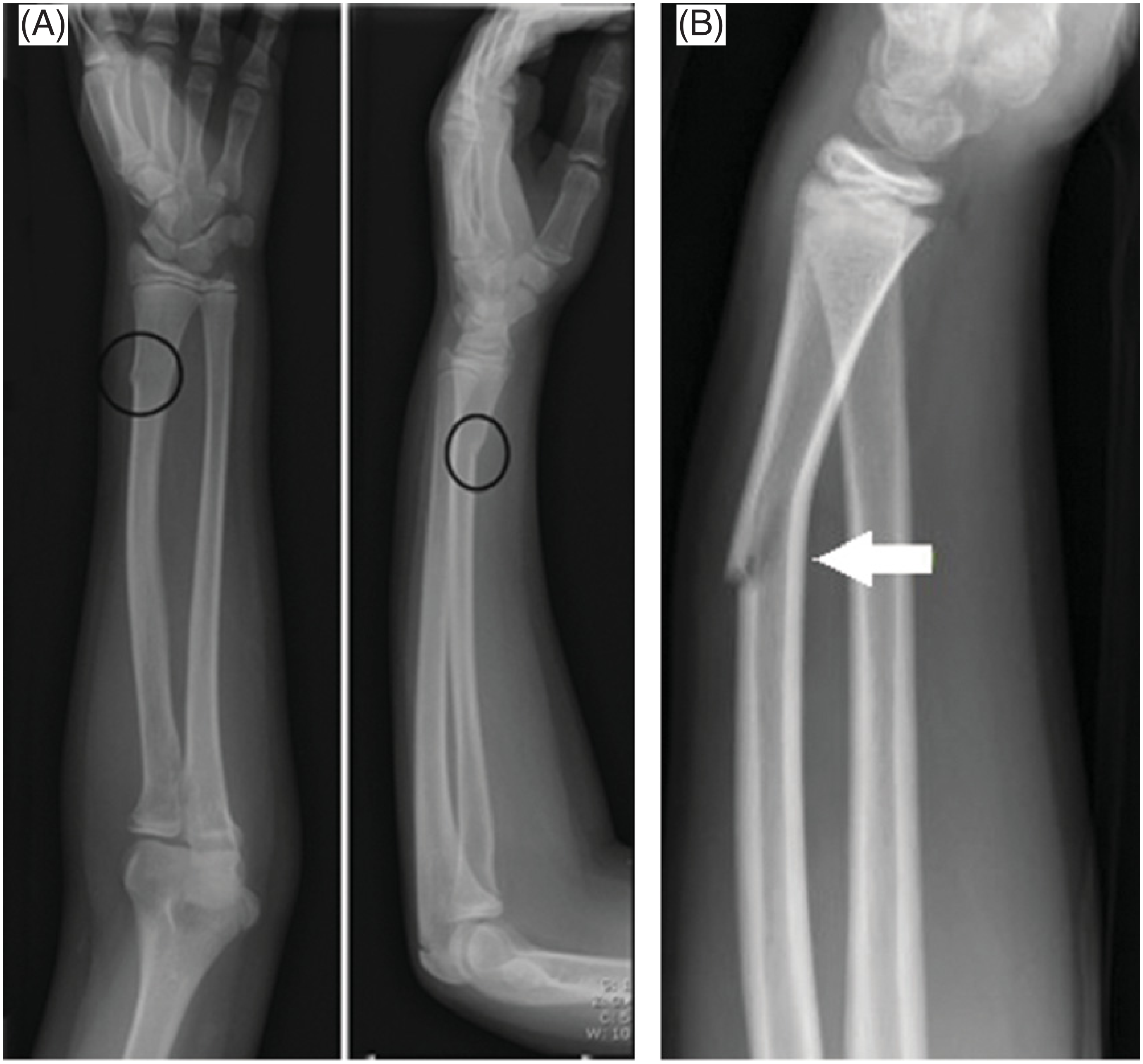


Figure 6.6 A,B Anteroposterior and lateral radiograph of a distal radius torus fracture (A). Lateral radiograph of a distal radius greenstick fracture (B).

Supracondylar Fracture

Distal humerus fractures that are proximal to the epicondyles are termed supracondylar fractures, and most often occur in children age 5–10 years. In children, the ligaments and joint capsule are stronger than the bone, and thus hyperextension injury often causes bone fracture, while adults with a similar mechanism often suffer a posterior dislocation of the elbow (Figure 6.7 A–C).

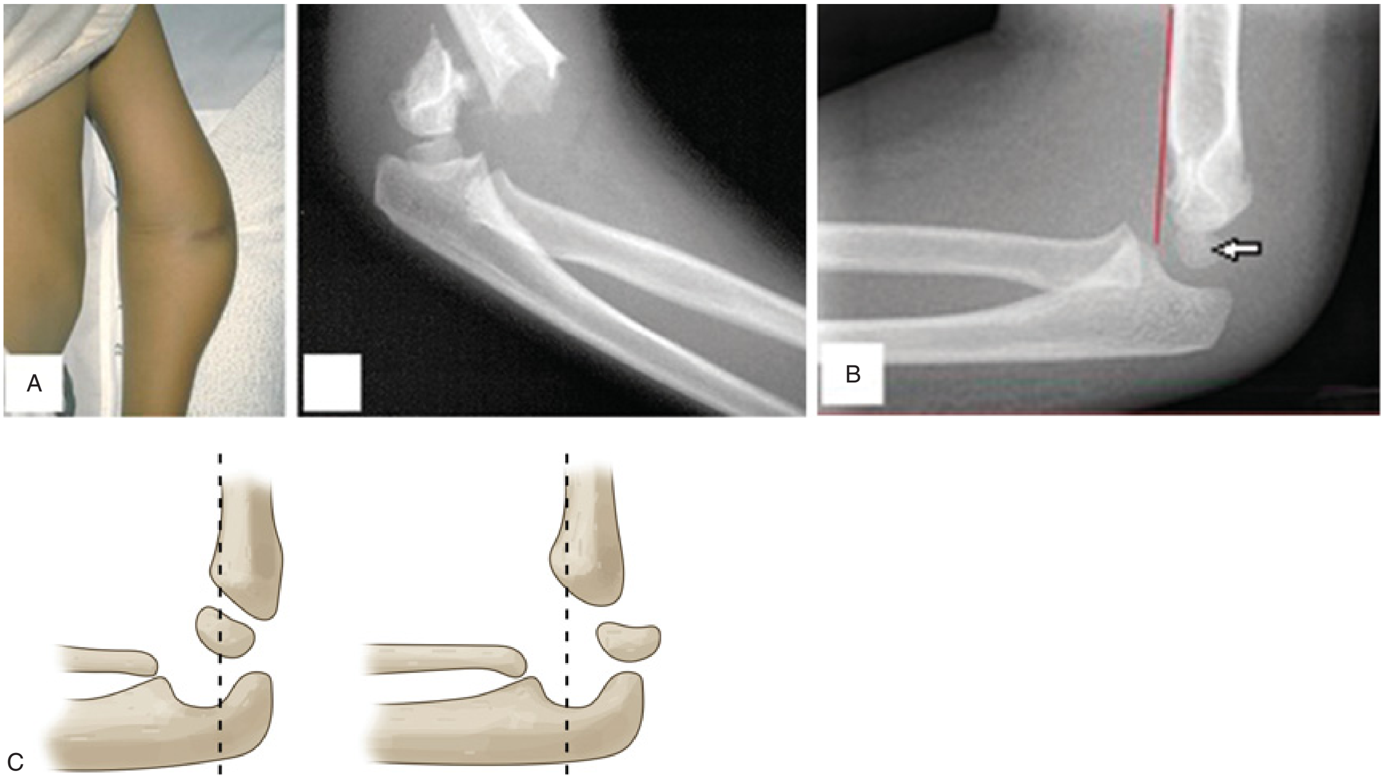


Figure 6.7 A–C Photograph of a swollen elbow of a child suffering a supracondylar fracture. Radiograph of the elbow shows displaced extension supracondylar fracture (A). Radiograph of a minimally displaced transverse supracondylar fracture with the anterior humeral line passing anterior to the capitellum (B). Illustration of the anterior humeral line. Normally this line intersects the middle of the capitellum. With an extension fracture, this line intersects the anterior one-third of the capitellum or passes entirely anteriorly (C).

There are two types of supracondylar fractures; the *flexion* type, which occurs less often, and the more common *extension* type. Extension injuries are often the result of a fall on an arm with the elbow fully extended. On exam, the elbow will be swollen, often with a joint effusion and with significant pain and tenderness. In addition, the olecranon will be more prominent, as it is attached to the posteriorly displaced distal fragment. Careful neurovascular examination of the arm is essential, as many of these fractures are complicated by brachial artery and median, radial, or ulnar nerve injury. In addition, compartment syndrome can be seen with displaced fractures and must be considered. If compartment syndrome continues unchecked, ischemic necrosis of muscle and nerves can result in Volkmann's contracture, leading to permanent dysfunction of the arm and hand. Consequently, children with supracondylar fractures are frequently admitted to the hospital for serial compartment checks.

Radiographically, these fractures are often detected on the lateral view of the elbow. Because many of these fractures are transverse, they may not be readily visible on the anteroposterior view. In addition, up to 25% are of the greenstick variety with the posterior cortex remaining intact. The only abnormality seen may be a posterior fat pad sign or an abnormal anterior humeral line. Supracondylar fracture must be suspected in any child with acute elbow trauma, swelling, and pain, in spite of normal radiography. Most nondisplaced fractures are treated nonoperatively with casting, while most displaced fractures undergo percutaneous pinning.

Amputations

Amputations are devastating injuries and require expert knowledge in the care of the patient and the amputated part. The area affected is important in the decision to attempt reimplantation. Lower extremity reimplantation is rarely indicated, given the frequency of associated crush injury and the efficacy of current prostheses. In contrast, upper extremity traumatic amputations, especially those involving the thumb, are often reimplanted, given the severe disability that occurs with the loss of that single digit. Time elapsed since the injury is an important consideration, as reimplantation is less likely to be successful if the warm ischemia time has been more than 6–8 hours. If the amputated segment has been properly cooled and cared for, then this window of time may be successfully extended to 12–24 hours. In addition, clean, sharp amputations are more likely to be successful than crush injuries. In general, all amputated parts should be considered for reimplantation, since even severely crushed parts can be used for skin coverage (Figure 6.8 A–F).

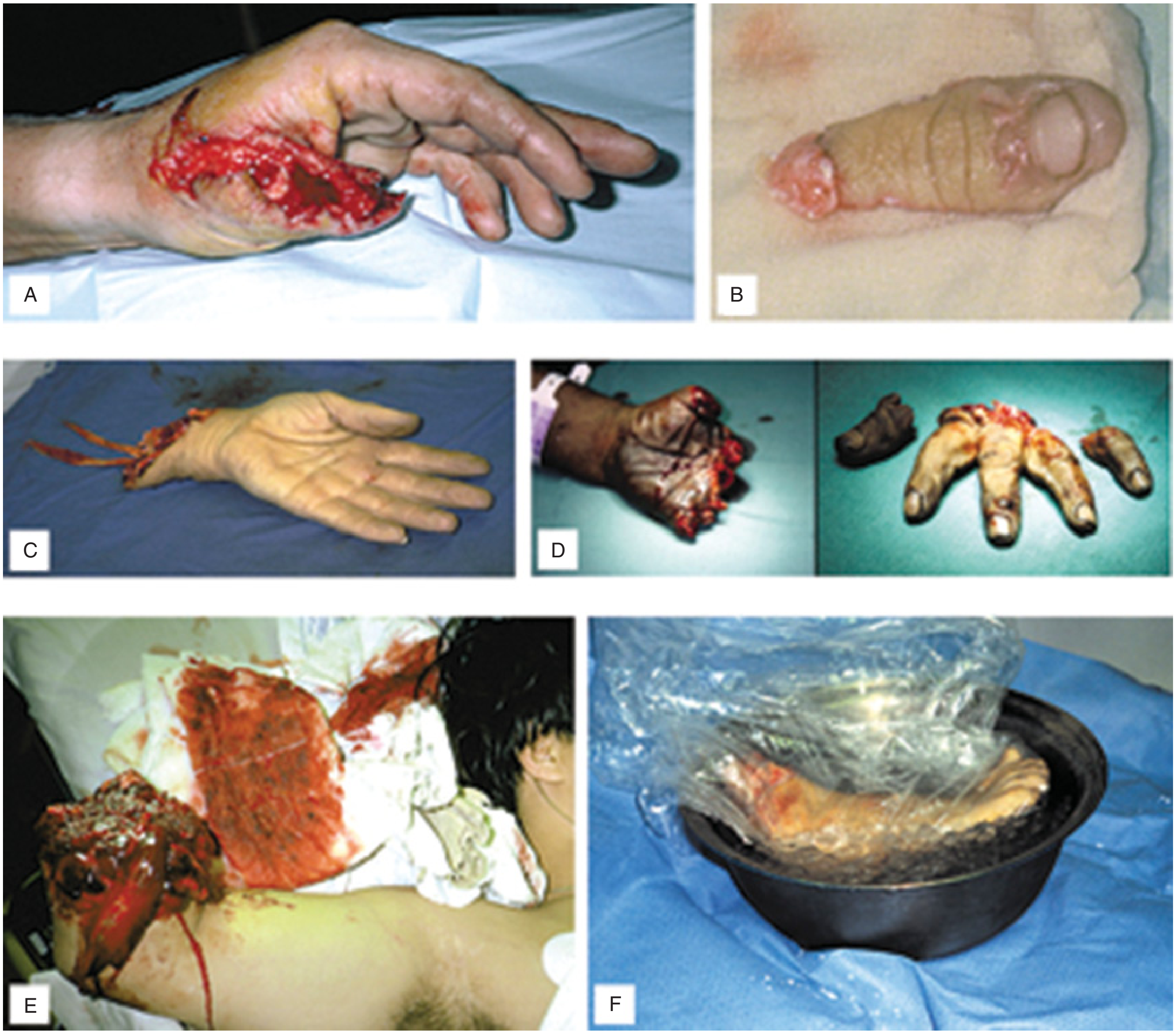


Figure 6.8 A–F Extremity amputations. Photograph of a hand with thumb amputated secondary to a power saw injury (A). The amputated part in saline-moistened gauze (B). Reimplantation was performed. Amputated hand and multiple fingers (secondary to the hand being caught in a gear mechanism). Reimplantation was performed (C, D). Amputated forearm. Reimplantation was performed (E). Amputated foot being cooled in ice-water slurry (F).

Proper care of the amputated part will maximize the chance of successful reimplantation. Avoid antiseptics, debridement, and excessive handling. Irrigate the amputated part with normal saline and then wrap it loosely in saline moistened sterile gauze. Place the gauze-wrapped part in a watertight plastic bag and place the bag in an ice-water mixture.

Similarly, irrigate the patient's stump with normal saline and apply direct pressure to control any bleeding. As with the amputated part, do not apply antiseptics to the stump. Administer broad-spectrum antibiotics and tetanus immunization as appropriate.

Tendon Injury

Tendon lacerations are important injuries to detect, and full examination of the hand will usually detect complete lacerations. Diagnosis of partial injuries is more difficult, as tendon function often remains intact. A careful examination of the laceration through the full range of motion is necessary, as the injured area of tendon may retract out of the field of view (Figure 6.9).

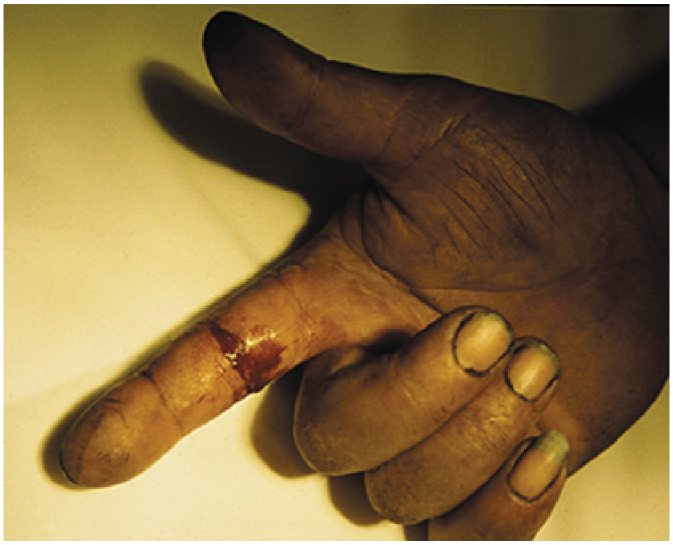


Figure 6.9 This photograph illustrates the classic position of extension in a patient with finger flexor tendon injury.

Flexor tendon repair in the hand is difficult and fraught with complications. Flexor tendon repair should be performed by an experienced hand surgeon in an operating room, whereas extensor tendon injuries of the hand and fingers can be repaired in the emergency department. Prophylactic antibiotics, tetanus immunization (if needed), and splinting are essential components of emergency management.

Peripheral Vascular Injury

Most peripheral vascular injuries occur as a result of penetrating trauma, with gunshot wounds being more damaging than stab wounds. Fortunately, blunt trauma rarely causes vascular injury except with markedly displaced fractures and dislocations. Prompt identification and repair is important, given the relatively short "golden period" of about 6 hours, after which irreversible ischemic insult will occur.

Physical examination is important for early diagnosis, and most authors divide examination findings into "hard" and "soft" signs. Hard signs of vascular injury include pulsatile bleeding, unexplained hypotension, absent peripheral pulse, expanding hematoma, palpable thrill, audible bruit, or evidence of regional ischemia, such as a pale, cool extremity. In the presence of any of these signs, operative exploration is usually recommended (Figure 6.10 A–D, Figure 6.11 A–D, Figure 6.12 A,B, Figure 6.13 A–D, Figure 6.14, Figure 6.15 A,B).

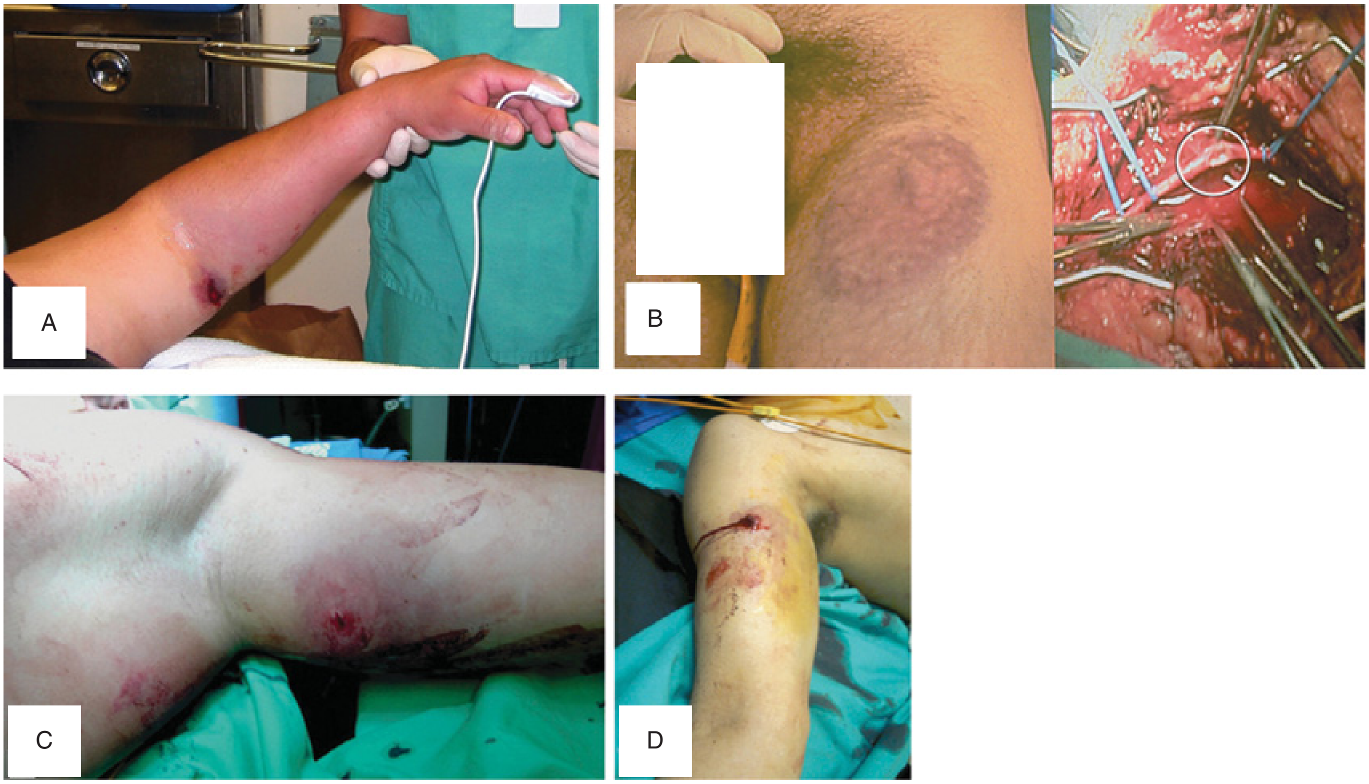


Figure 6.10 A–D Photograph of a patient with a gunshot wound of the elbow with obvious demarcation of cyanosis distally and absent distal pulses. Pulse oximetry is being used but is not sensitive for detecting vascular injury (A). Gunshot wound with an entry in the posterior thigh and a large groin hematoma anteriorly. The left foot was cool and pale (left). Operative view revealing associated femoral artery injury (right; B). Patients with gunshot wounds to the arm with large hematomas and diminished peripheral pulses. Both patients had injury to the brachial artery (C, D).

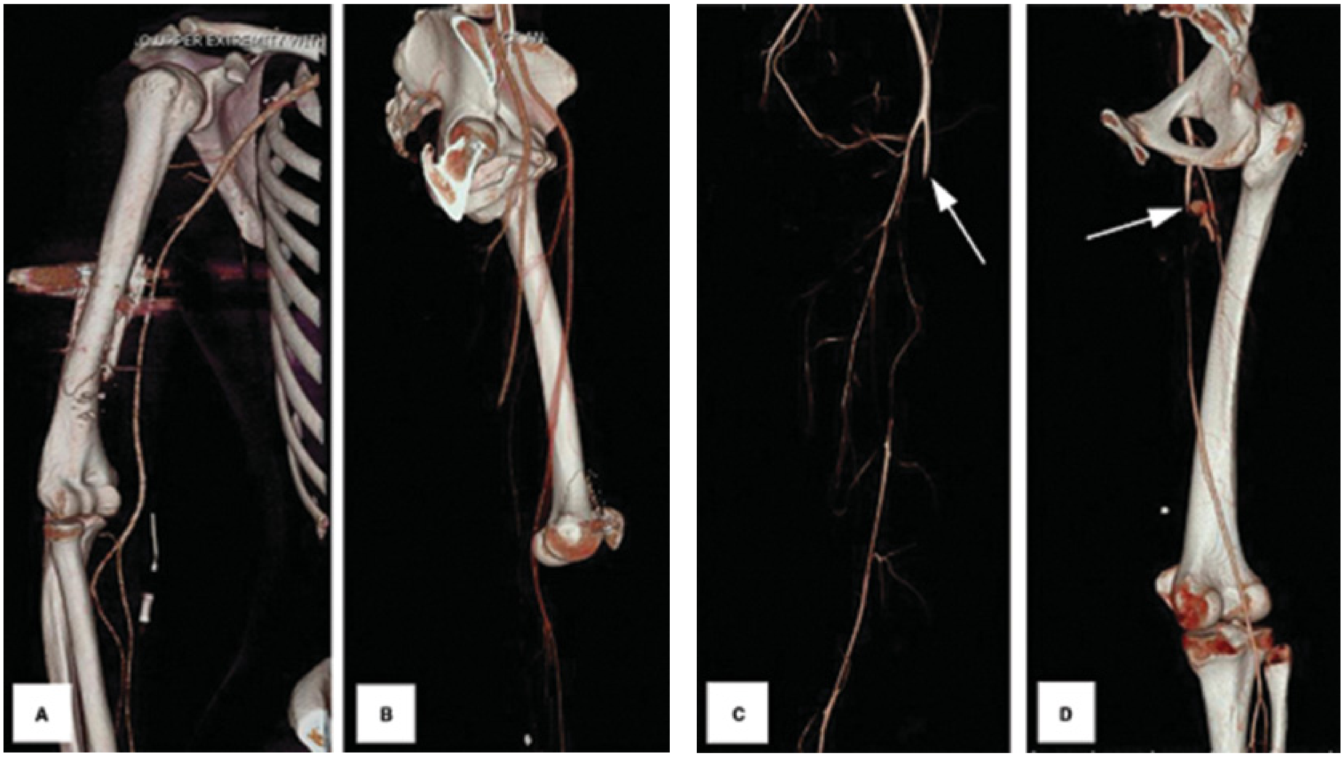


Figure 6.11 A–D Gunshot wound to the arm with a bullet tract near the brachial vessels (A). CT angiogram with 3-D reconstruction shows a normal brachial artery. Gunshot wound to the thigh with a stable hematoma (B). CT angiogram with 3-D reconstruction shows a normal superficial artery. Patients with gunshot wounds to the upper thigh. In both patients, CT angiography with 3-D reconstruction shows transection and thrombosis of the superficial femoral artery (arrow; C, D).

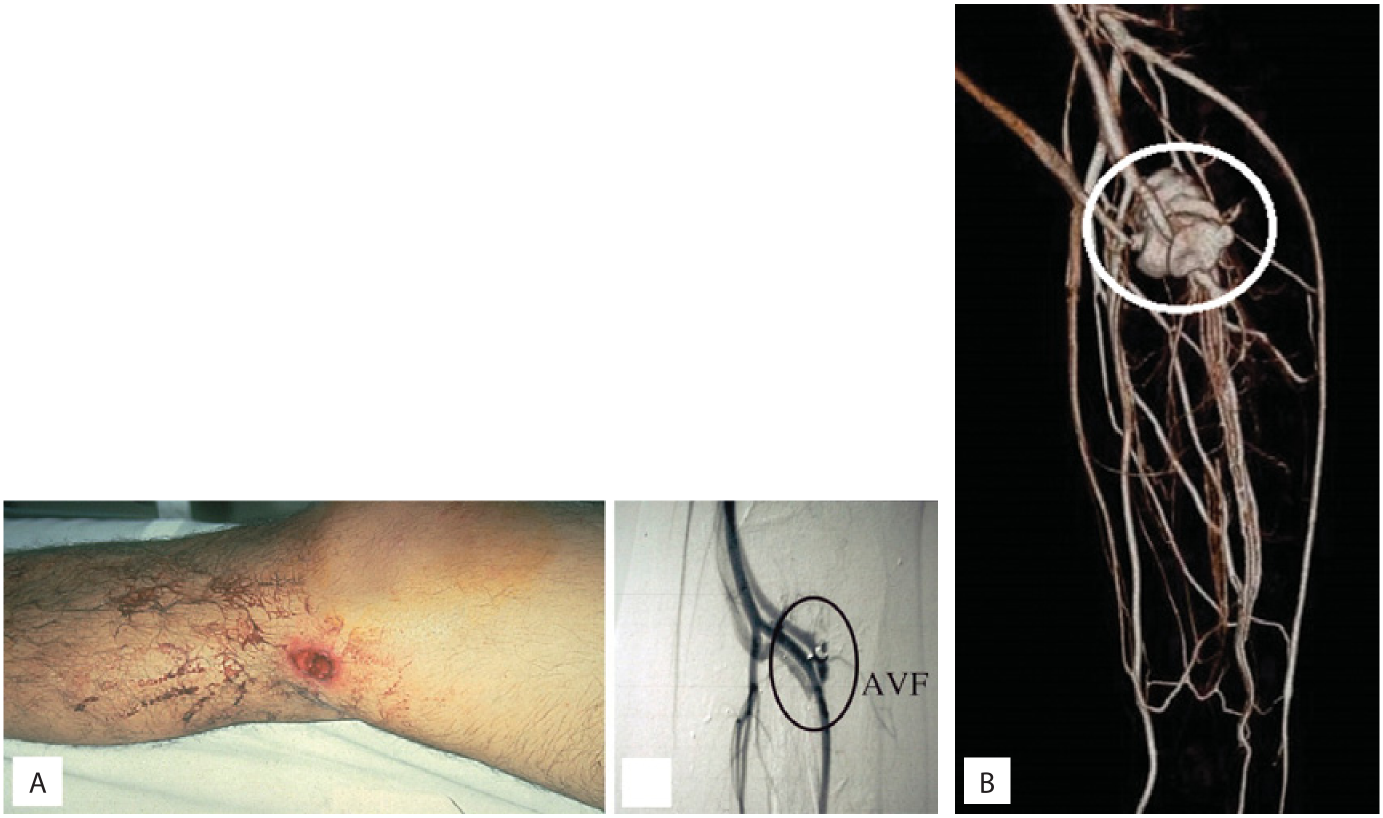


Figure 6.12 A,B Gunshot wound to the knee. The patient had diminished peripheral pulses and a bruit on auscultation. Angiography shows an arteriovenous fistula (circle; A). Patient with a stab wound to the right antecubital fossa presenting with a large hematoma, diminished peripheral pulses, and a bruit on auscultation. CT angio shows false aneurysm of the distal brachial artery and an arteriovenous fistula (circle; B).

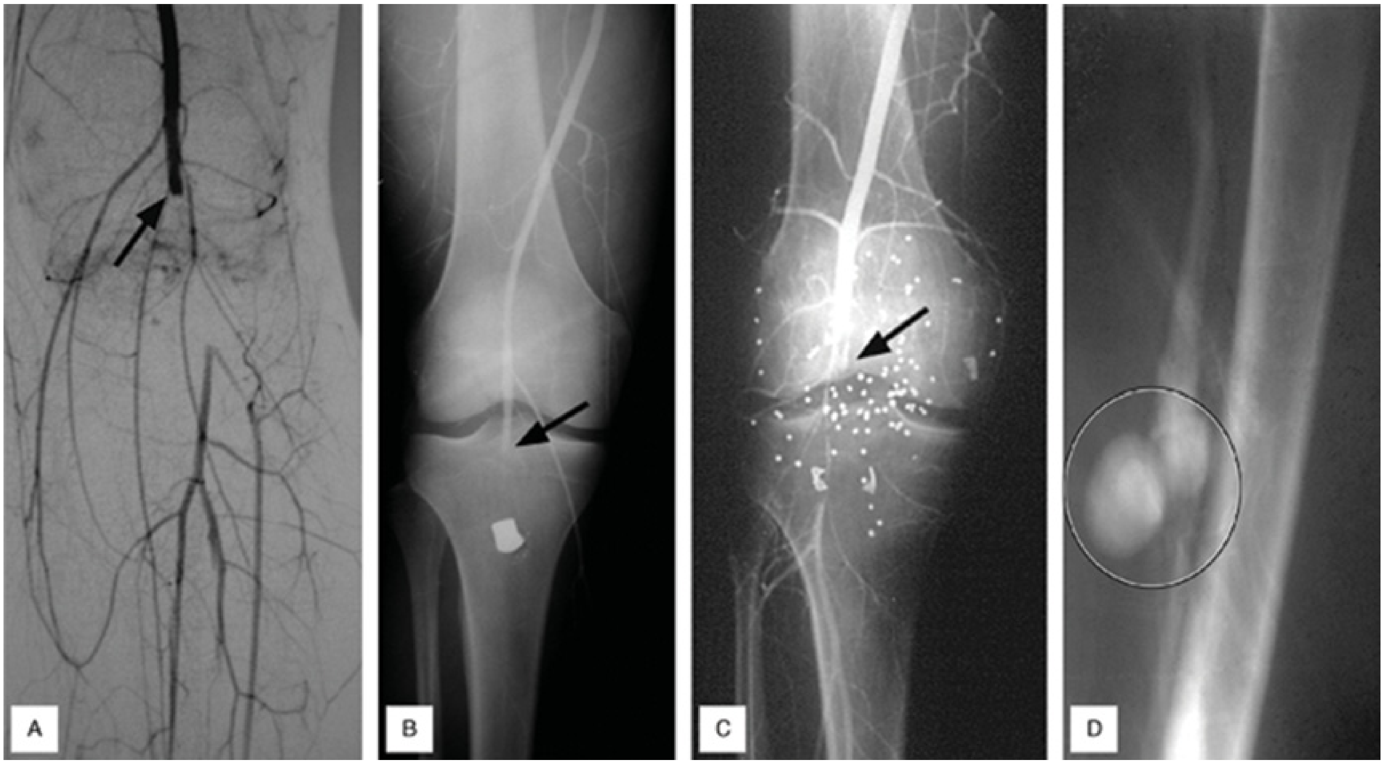


Figure 6.13 A–D Gunshot wound to the knee and no peripheral pulse on palpation (A). Angiography shows transection and thrombosis of the popliteal artery (arrow). Collateral vessels provide a satisfactory peripheral perfusion. Gunshot wound to the popliteal fossa with no peripheral pulse (B). The leg was cold. Angiography shows transection and thrombosis of the popliteal artery (arrow). Note the absence of collateral circulation. Shotgun injury to the knee with absent peripheral pulses. Angiography shows transection and thrombosis of the popliteal artery (arrow; C). Gunshot wound to the mid-thigh (D). The patient had diminished peripheral pulses and a bruit on auscultation. Angiogram shows injury to the superficial femoral artery and a pseudoaneurysm (circle).

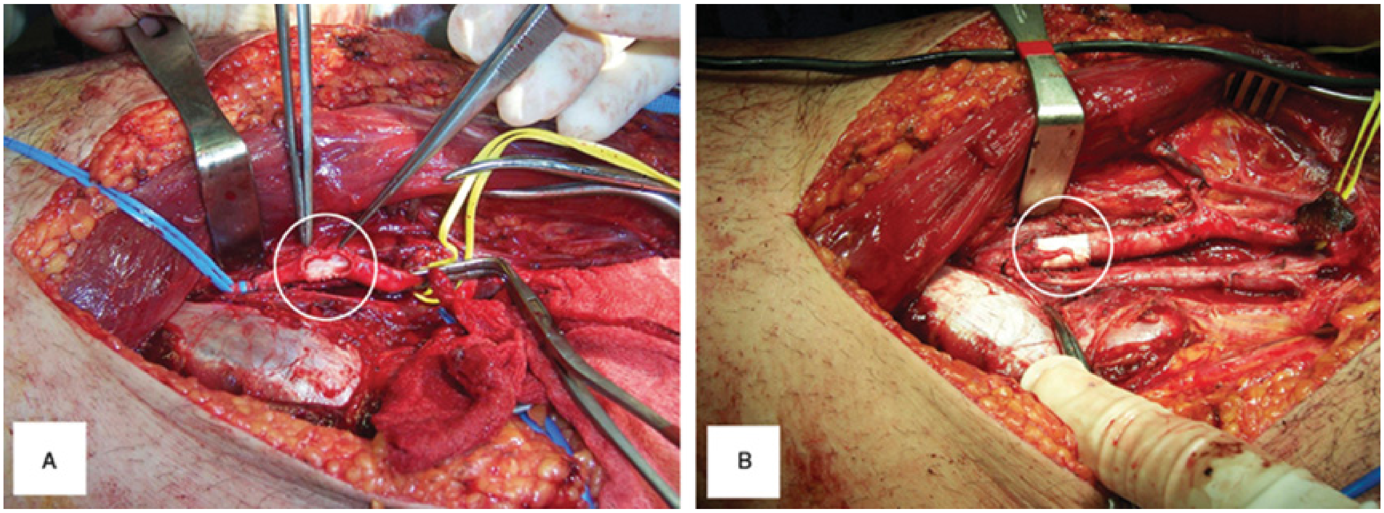


Figure 6.14 Gunshot wound to the thigh with severe active bleeding. Intraoperative photograph shows an injury to the superficial femoral artery (circle; A). The vessel was repaired with a synthetic graft (circle; B).

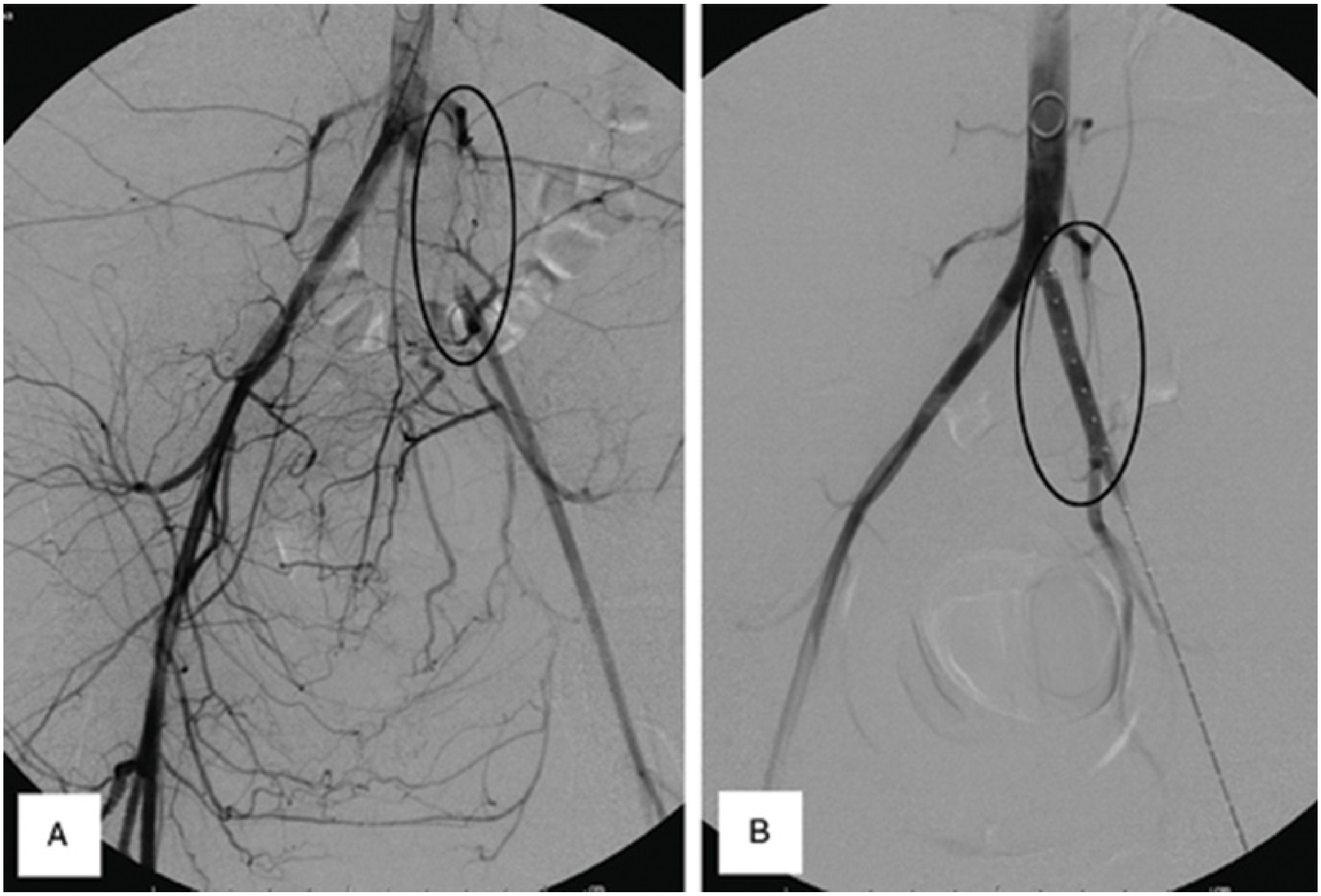


Figure 6.15 A,B Patient with complex pelvic fractures and absent femoral pulse. Angiography shows thrombosis of the left common iliac artery (circle; A). The thrombosis was successfully managed with an angiographically placed stent-graft (circle; B).

Soft signs include moderate hematoma formation, injury in proximity to major neurovascular tracts, peripheral nerve injury, and diminished but palpable pulses. To assist the evaluation of diminished pulses, the API is often used to screen for injury. An index of >0.9 generally excludes significant injury, and an index of <0.9 mandates further investigation. Though there are variations in the stepwise approach, all patients with soft signs should undergo further diagnostic testing such as color flow doppler, ultrasound, or arteriography to exclude serious injuries requiring operative attention. CTA has become the investigation of choice and has replaced conventional angiography in most cases. It is highly specific and sensitive, not invasive, and can be performed during routine CT scanning.

Besides acute limb loss, patients with peripheral vascular injuries are also at risk for acute compartment syndrome. Late complications of missed injuries include pseudoaneurysm formation, delayed thrombosis, arteriovenous fistula, and intermittent claudication.

Peripheral Nerve Injury

Peripheral nerve injuries, though not life-threatening, can cause significant long-term disability. Nerve injuries are generally classified in the following three groups:

1. Neuropraxia: Mild transient nerve dysfunction without gross anatomic disruption to the nerve, often secondary to contusion, local ischemia, or prolonged local pressure.
2. Axonotmesis: More extensive injury with interruption of axons, but with preservation of the neural sheath. Complete loss of motor and sensory function is seen distal to the site of injury. Spontaneous recovery is possible and is dependent on the distance between the site of injury and the peripheral muscles to be reinnervated.
3. Neurotmesis: Complete severance of the nerve or damage to the point where spontaneous regeneration is impossible. This injury is often seen following direct lacerations, severe contusions, crushing or ischemic compressive injuries, electrical and thermal burns, and chemical injuries (Figure 6.16 A–D).

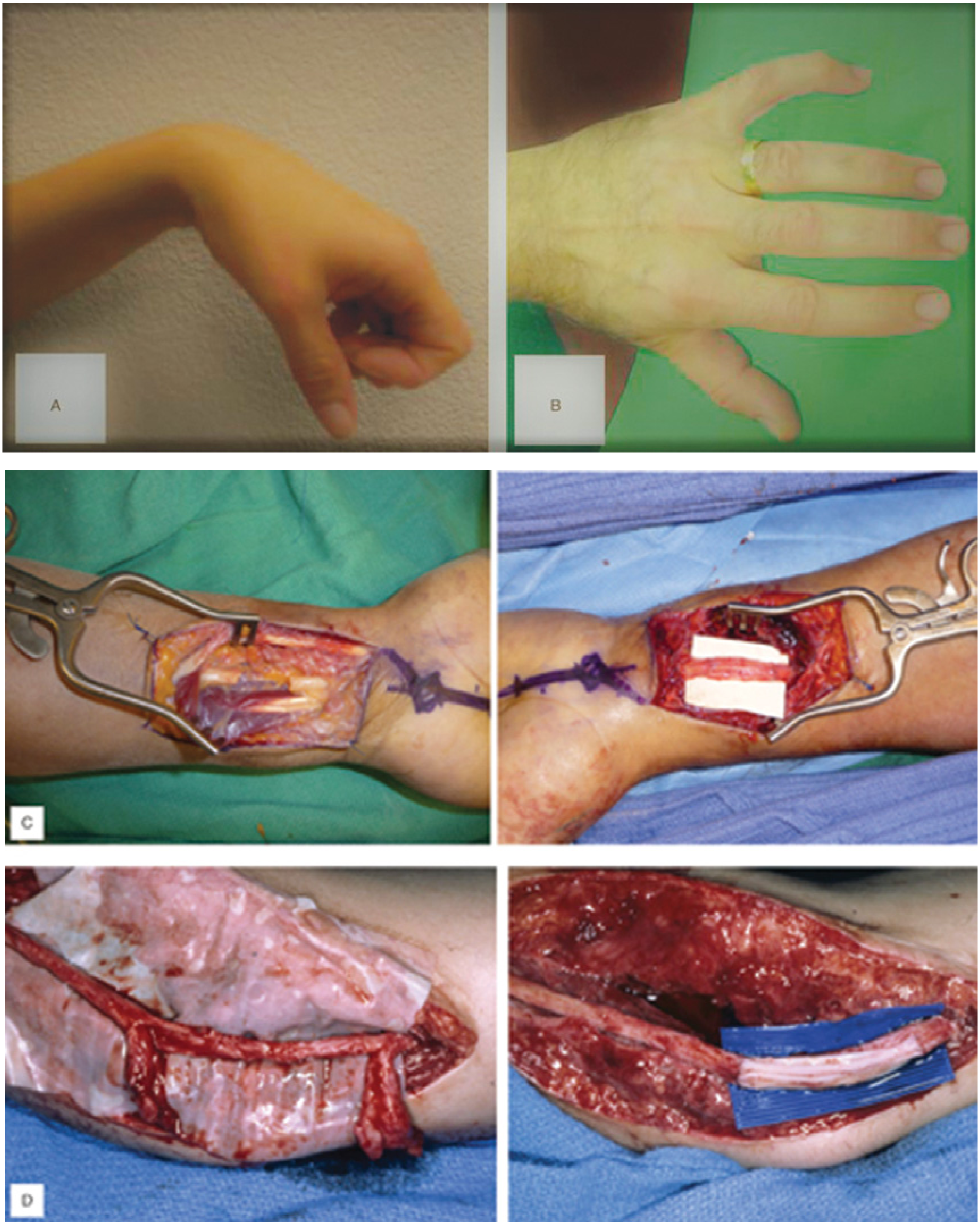


Figure 6.16 A–D Peripheral nerve injuries in the upper extremity. Proximal radial nerve injury with the characteristic wrist drop (A). Ulnar nerve injury with the characteristic abduction and slight flexion of the small flnger (B). Operative view of a transected median nerve before (left) and after repair (right; C) (photograph courtesy of Dr. Milan Stevanovic). Operative view of a partially transected ulnar nerve before (left) and after repair (right; D).

Metacarpal Fractures

Metacarpal fractures are commonly seen in the emergency department and are often secondary to direct force, such as a clenched fist injury. Fourth and fifth metacarpal neck fractures of this nature are often referred to as “boxer’s fractures.” Metacarpal fractures can be classified in four types:

1. Head fracture: Rare injury.
2. Neck fractures: Very common fracture with the apex of the fracture being dorsal. Second and third metacarpal fractures require accurate reduction for good hand function, while fourth and fifth metacarpal fractures can heal with angulation up to 35 and 45 degrees, respectively.
3. Shaft fractures: Can be transverse, oblique, spiral, or comminuted. Rotational deformities can occur especially with oblique and spiral fractures, and will need identification and correction. This is best evaluated clinically by having the patient flex the fingers into a fist. Rotational deformities will be recognized by an abnormal lie of the affected digit. Normally the fingers of the flexed hand all point toward the scaphoid bone at the wrist.
4. Base fractures: Uncommon fractures that are usually stable (Figure 6.17 A–D).

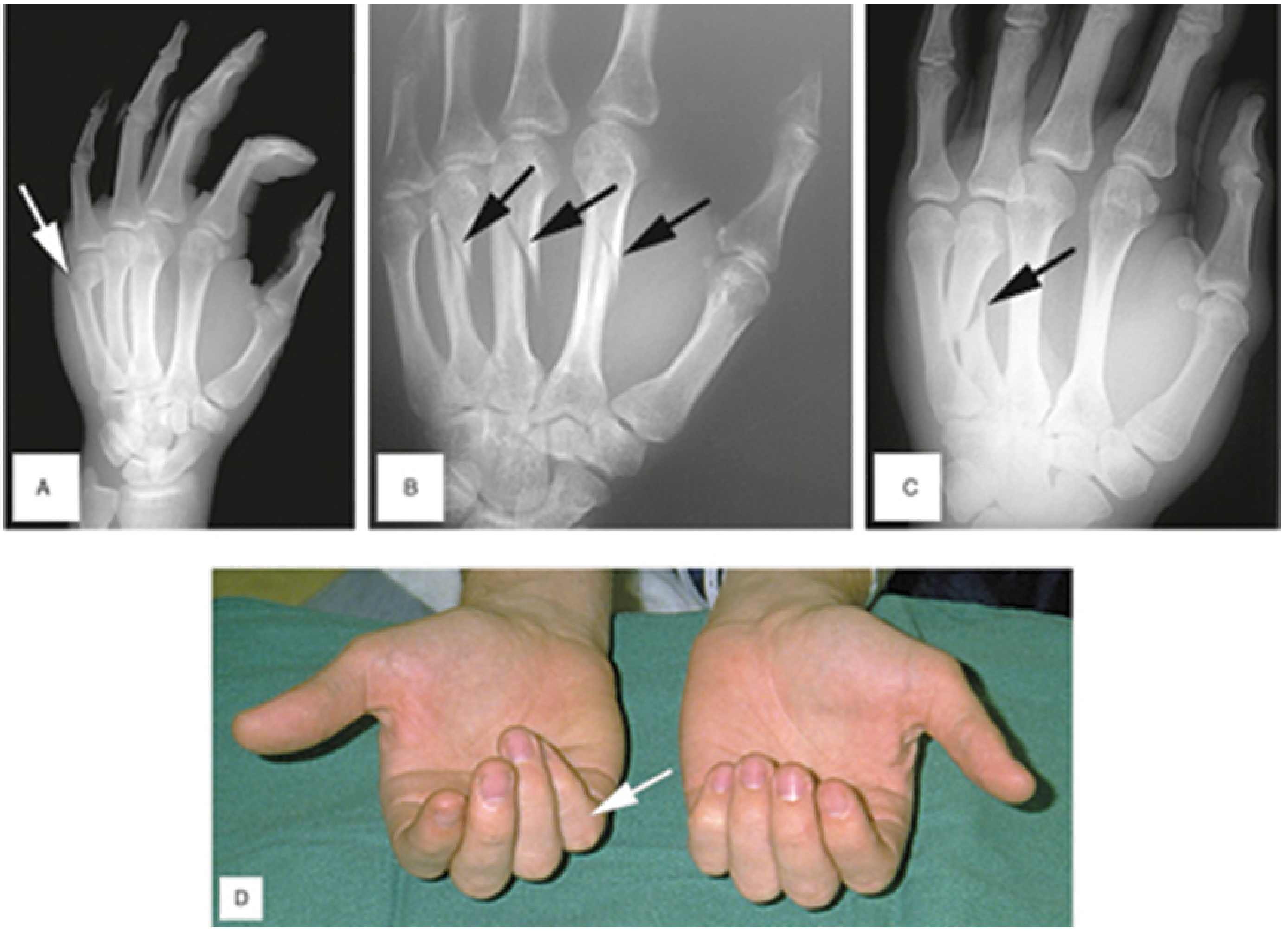


Figure 6.17 A–D Metacarpal fractures. Radiograph of a boxer’s fracture of the fifth metacarpal bone (A). Radiograph of oblique fractures of the second, third, and fourth metacarpal bones (B). Radiograph of a displaced oblique fracture of the fourth metacarpal (C). Photograph of a rotational fracture of the right fifth metacarpal. All fingertips should normally point toward the scaphoid (D).

Most metacarpal fractures will have closed reduction, although comminuted, spiral, and oblique fractures may need operative fixation.

First Metacarpal Fractures (Bennett’s and Rolando’s Fractures)

First metacarpal fractures are classified as articular or, less commonly, nonarticular, with the latter being either transverse or oblique. Articular fractures are further described in two common patterns (Figure 6.18 A,B).

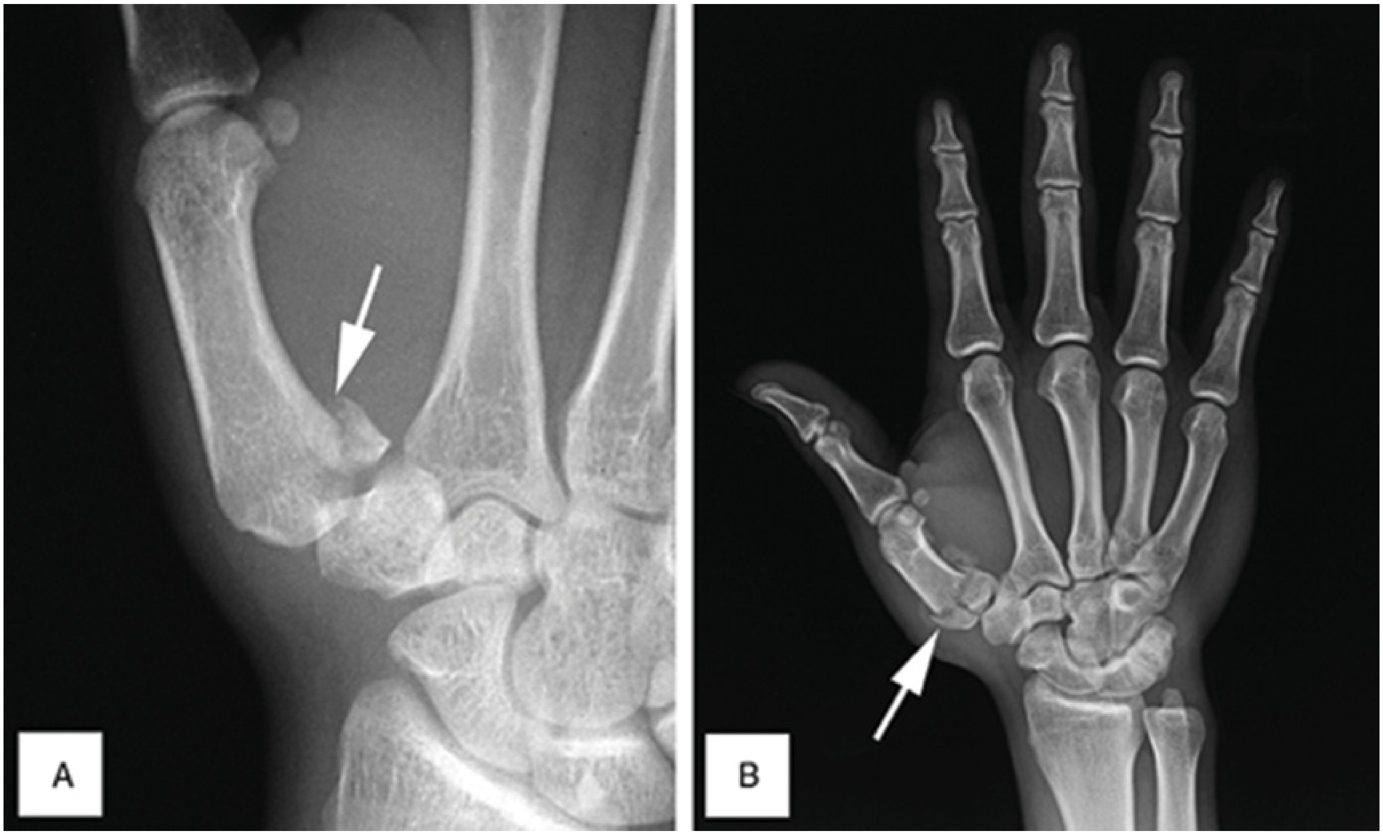


Figure 6.18 A,B First metacarpal fractures. X-ray of a Bennett's fracture (arrow; A). X-ray of a Rolando's fracture (arrow; B).

Bennett's fracture is an oblique fracture involving the carpometacarpal joint. It is usually due to direct axial force on a partially flexed thumb, such as in a fistfight. The characteristic finding is a small triangular proximal fragment that remains anatomically correct while the shaft is displaced in a dorsal–radial fashion by the pull of the abductor pollicis longus and the abductor pollicis brevis. Anatomic reduction is essential, so these fractures are usually treated with percutaneous pinning or even open reduction.

Rolando's fracture is a comminuted fracture at the base of the first metacarpal. It is a relatively rare fracture, often caused by a similar mechanism to a Bennett's fracture. The treatment is controversial and may vary from closed to open reduction, depending on the degree of comminution and displacement.

Scaphoid Fractures

Fractures of the scaphoid bone are common and usually occur from a fall on an outstretched hand. There is pain and tenderness in the anatomic snuffbox; applying an axial load along the first metacarpal increases the pain.

Scaphoid fractures are classified as proximal third, middle third, and distal third fractures. The proximal third of the scaphoid does not have its own blood supply, and thus these fractures are particularly at high risk for avascular necrosis if treatment is delayed or improper. Plain X-rays are often diagnostic, but up to 20% may present with normal X-rays initially. Treat patients with scaphoid tenderness and normal X-rays with a thumb spica splint and close follow-up. A CT scan may be done in 3 days, or the patient may have repeat X-rays in 10 days to detect occult fractures. Nondisplaced scaphoid fractures are treated with thumb spica immobilization, while displaced or unstable fractures often need open reduction (Figure 6.19 A).

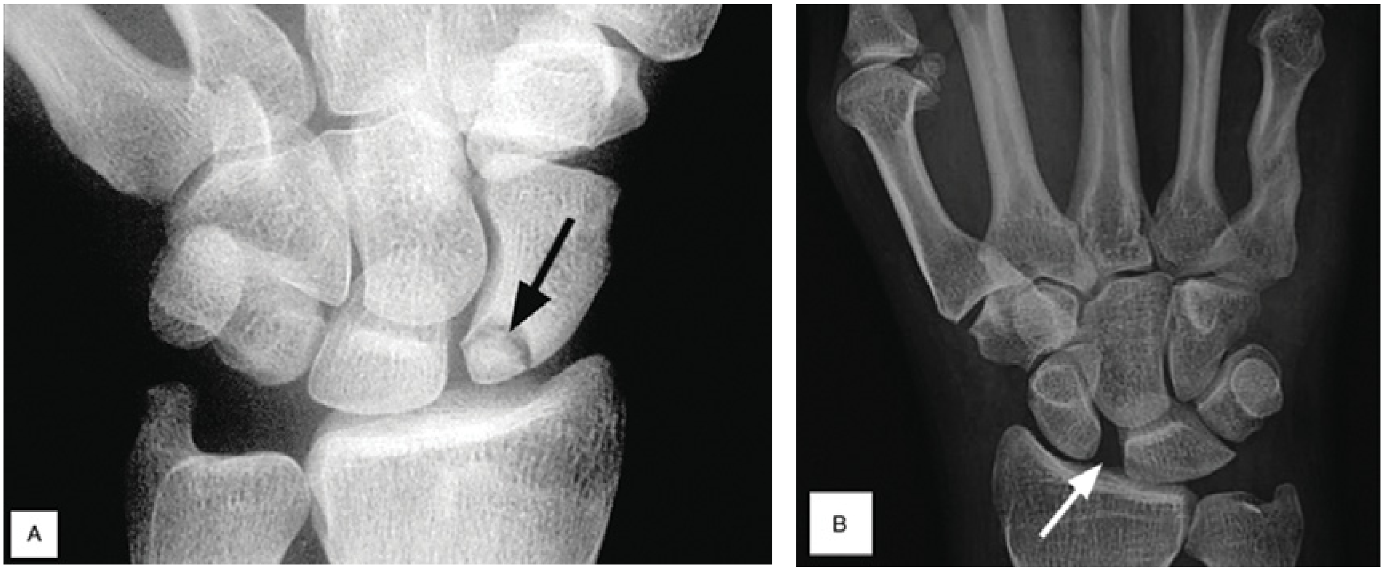


Figure 6.19 A,B X-ray of a proximal one-third scaphoid fracture (arrow; A). This fracture is particularly at high risk for avascular necrosis if treatment is delayed. Scapholunate dislocation. Note the widening of the joint space between the scaphoid and the lunate (arrow; B).

Scapholunate Dislocation

Scapholunate ligamentous injury is often secondary to forced dorsiflexion of the wrist, as occurs in a fall on an outstretched hand. There is pain and tenderness on the radial aspect of the wrist, just distal to Lister's tubercle.

This injury is commonly missed, and radiographs should be carefully examined for an abnormal gap between the scaphoid and lunate on the posteroanterior view (Figure 6.19 B). This joint space is normally less than 3 mm, and any widening of this space is suggestive of a scapholunate ligamentous injury. Scaphoid dislocation may be treated with closed reduction and percutaneous pinning or may require open reduction. Missed scapholunate injuries often cause chronic arthritis and pain or may cause ischemic necrosis of the lunate (Keinbock's disease).

Lunate and Perilunate Dislocation

Lunate and perilunate dislocation are relatively uncommon injuries that can easily be missed if the treating physician is not familiar with normal carpal relationships. The injury often involves high energy, such as a fall or a motor vehicle crash, which causes extreme hyperextension, ulnar deviation, and midcarpal dorsiflexion (Figure 6.20 A–D).

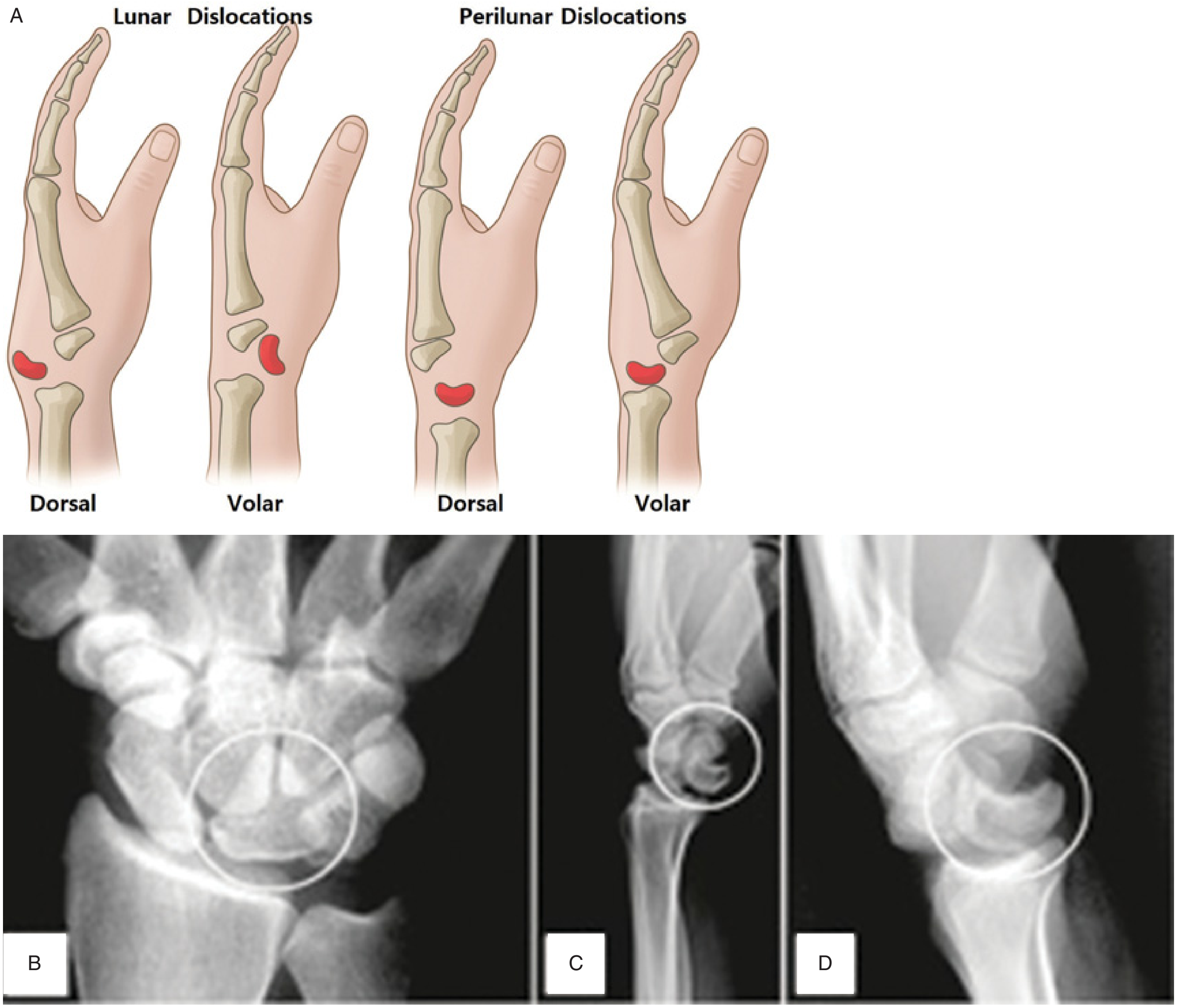


Figure 6.20A–D Illustration of the types of lunate and perilunate dislocations (A). Anteroposterior X-ray of the wrist showing a lunate dislocation with a "piece of pie" lunate bone (B). Lateral radiograph view of the wrist with a volar lunate dislocation (C). Lateral radiograph view of the wrist with a dorsal perilunate dislocation (D).

In the normal wrist, the lateral view reveals that the distal radius, lunate, and capitate align themselves forming three Cs atop each other. This relationship is significantly altered with a lunate or perilunate dislocation, and thus a lateral radiograph usually reveals the injury pattern.

A lunate dislocation will demonstrate the lunate pushed off the distal radius in a "spilled teacup" sign on the lateral view. On the anteroposterior view, the lunate will appear as a "piece of pie" sign. A perilunate dislocation demonstrates a capitate that is posterior or anterior to the lunate, while the lunate maintains contact with the distal radius. The anteroposterior view is less specific and shows an obliterated joint space between the lunate and the capitate. Treatment involves anatomical alignment with closed reduction, though open reduction may be necessary.

Wrist Fractures

1. Colles's Fracture

A Colles's fracture is the most common fracture of the wrist. It is a transverse fracture of the distal radius metaphysis, which is dorsally displaced and angulated. The fracture may also be intra-articular and/or have an associated fracture of the ulnar styloid (Figure 6.21 A).

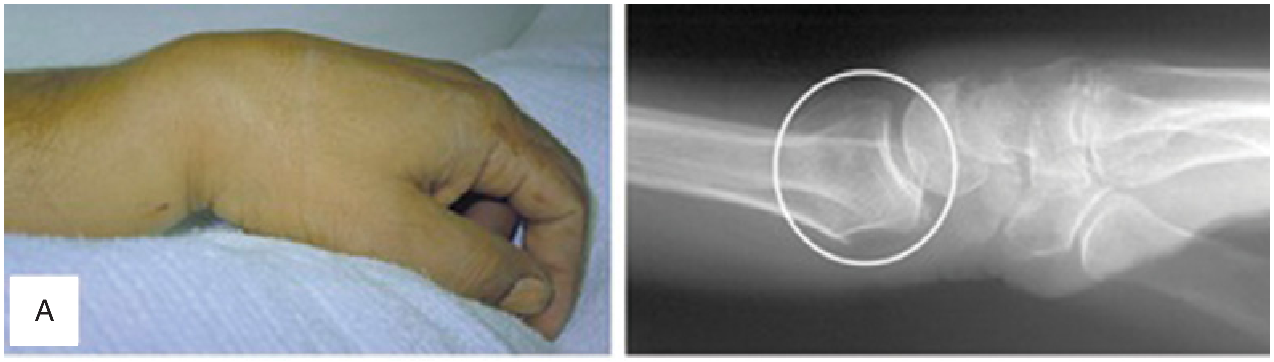


Figure 6.21A Colles's fracture. Photograph of the classic "dinner fork" deformity seen with dorsal radius fractures (left). Lateral wrist radiograph of a Colles's fracture (right).

The usual mechanism is a fall on an outstretched hand, and the wrist may demonstrate the classic "dinner fork" deformity on exam. The treatment is usually closed reduction, though more comminuted and displaced fractures will need open reduction and internal fixation.

2. Smith Fracture

A Smith fracture is a distal radius fracture with volar displacement of the distal fracture fragment and is often referred to as a "reverse Colles's fracture." It results from a fall on a flexed wrist or a direct blow to the dorsum of the wrist. Closed reduction will usually yield acceptable results, although intra-articular Smith fractures often undergo open reduction.

3. Barton Fracture

Barton fracture is a distal radius fracture in which the carpus displaces volarly with the radial fragment. A reverse Barton fracture is actually more common in which the carpus displaces dorsally with a fragment of the distal radius. Open reduction and internal fixation are usually performed for both these fractures because both involve intra-articular fractures (Figure 6.21B).

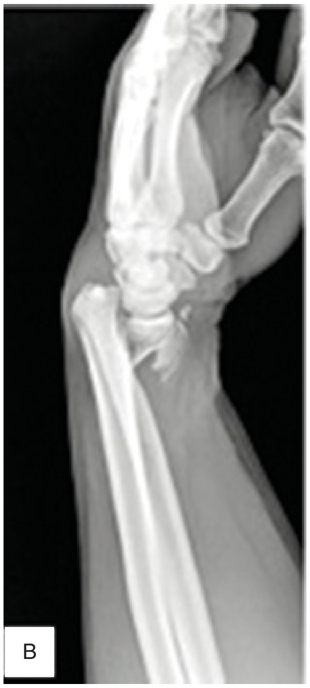


Figure 6.21 B Radiograph of a volar Barton fracture. The carpus displaces anteriorly with the distal radius fragment.

Forearm Fractures

When evaluating forearm fractures, it is important to remember that isolated fractures in this area are rare. Injuries often encompass two fractures at similar or separate sites or may involve a single fracture with ligamentous injury, with or without dislocation. Careful examination of the wrist and elbow joints is imperative, as these are commonly involved sites. Some common patterns are seen in forearm fractures and thus knowledge of these injury patterns is important.

Fractures involving both the radius and ulnar shafts are often seen in children secondary to falls on an outstretched hand. They are only rarely seen in adults and are then from high-energy mechanisms or severe direct impact. In a child, radiographs can reveal buckle or torus fractures, incomplete fractures (e.g., greenstick fractures), complete fractures, or a combination. Closed reduction is often successful in children because small amounts of residual angulation will resolve with bone remodeling. Complete fractures are more common in adults, and open reduction is often required.

The Monteggia fracture complex, first described in 1814, is a proximal ulnar fracture with an associated radial head dislocation. It is uncommon, representing only 7% of all forearm fractures. The injury is caused by forced pronation of the forearm during a fall on an outstretched hand. Radial nerve function should be examined as the radial nerve is commonly injured. Radiographs easily reveal the proximal ulnar fracture, and in these cases, the radial head should be carefully evaluated. In the normal position, the radial head should align with the capitellum when a line is drawn through the radial shaft. Monteggia fractures are treated with open reduction.

The Galeazzi fracture complex is a distal fracture of the radius with an associated dislocation or subluxation of the distal radial–ulnar joint. The injury occurs with a fall on an outstretched hand with the wrist in extension and the forearm forcibly pronated, or with a direct blow to the dorsoradial aspect of the wrist. The incidence of this fracture is similar to the Monteggia fracture complex, accounting for 7% of all forearm fractures. The anteroposterior radiograph reveals a fracture of the radius at the junction of the middle and distal thirds and, frequently, a widening of the joint space between the distal radius and ulna. The lateral view will demonstrate dorsal angulation of the radial fracture, and the head of the ulna will be displaced dorsally. Galeazzi fractures are unstable and require operative fixation.

Isolated ulnar shaft fractures or nightstick fractures are relatively common. They occur as a result of direct force to the ulna, often happening when raising one's arm in natural defense to a blow from an object such as a stick or club. In proximal ulnar fractures, the radial head should be carefully examined to exclude the presence of a Monteggia fracture. Associated injuries are rare, but include compartment syndrome and vascular injury. Most nondisplaced fractures are treated with plaster immobilization, while displaced fractures (>50% of the width of ulna) may need open reduction (Figure 6.22 A–D).

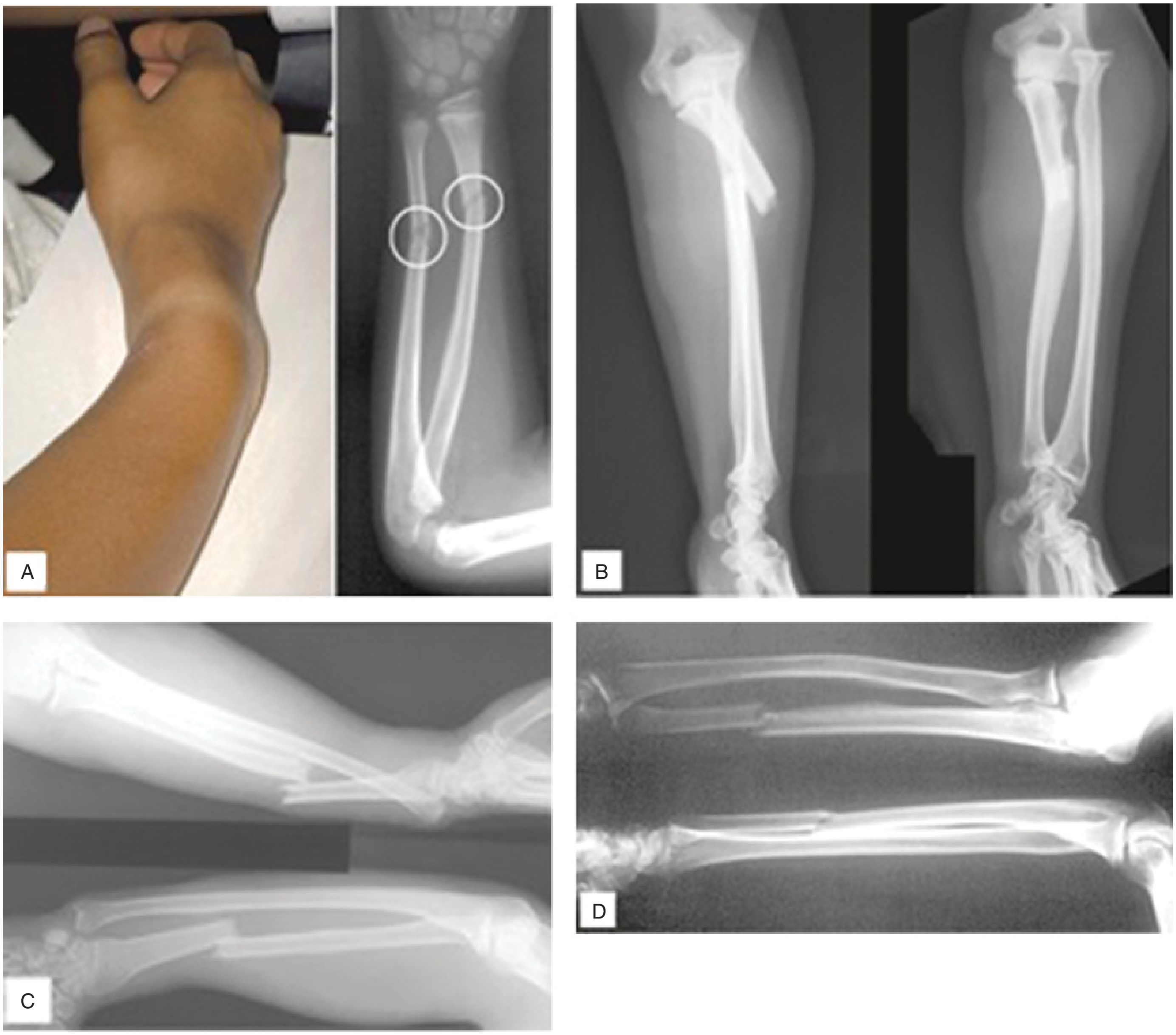


Figure 6.22 A–D Photograph and radiograph of a child with a "both bones" fracture (A). Anteroposterior and lateral radiographs of a Monteggia fracture (B). Anteroposterior and lateral radiographs of a Galeazzi fracture (C). Anteroposterior and lateral radiographs of a nightstick fracture (D).

Elbow Dislocation

Elbow dislocations account for about 20% of all dislocations and are the next most common dislocation after the shoulder and fingers. They are usually the result of a fall on an outstretched hand with the arm extended and abducted. Most elbow dislocations (>90%) are posterior, and the patient will present with the elbow in 45 degrees of flexion, with a prominence of the olecranon process posteriorly. The collateral ligaments are torn, and careful neurovascular assessment is important, as brachial artery and median nerve injuries can complicate this injury (Figure 6.23).

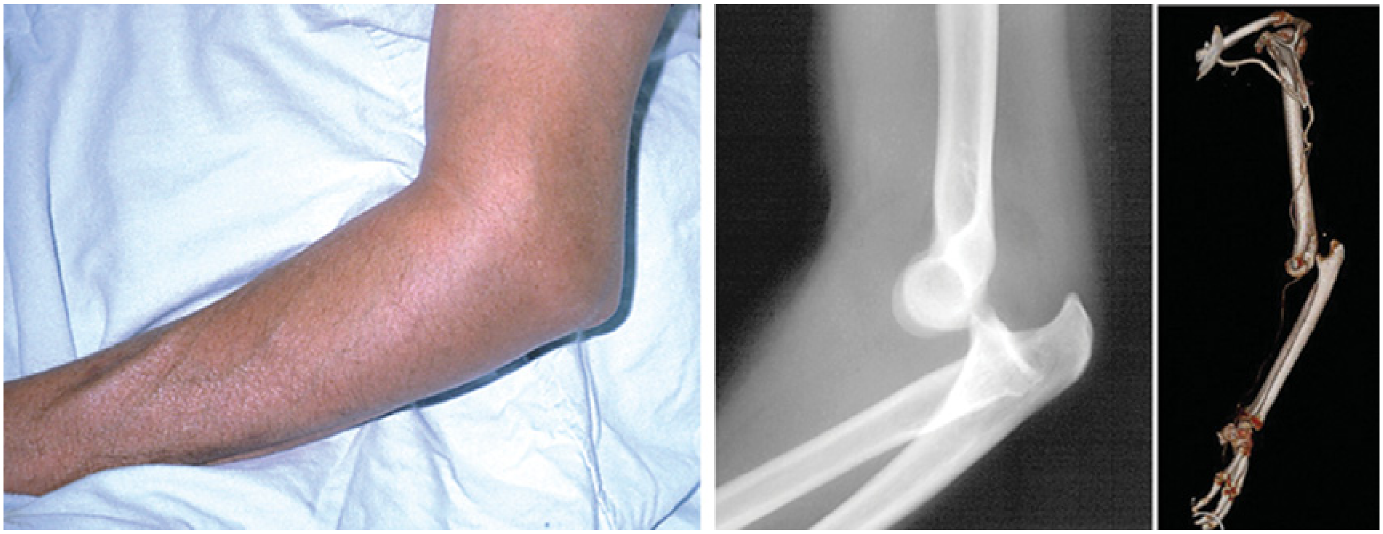


Figure 6.23 Posterior elbow dislocation: elbow photograph, X-ray, and 3-D reconstruction of patient with posterior elbow dislocation.

X-rays will reveal a dislocation. Most often the coronoid process will slip posteriorly, but occasionally a fracture of the process will be noted. Reduction is performed using procedural sedation by countertraction with flexion of the elbow.

Radial Head Fracture

Radial head fractures are common injuries of the elbow that usually result from a fall on an outstretched hand or by direct trauma. The injury can result in damage to the articular surface, depression of the radial head, or an angulated fracture of the radial head and neck. Often a fracture is seen on radiographs, but they may reveal only a “fat pad sign” indicative of an effusion and an occult fracture. Nondisplaced or minimally displaced fractures are treated with a sling or posterior splint. Fractures that are displaced more than 3 mm or involve more than one-third of the joint surface are usually treated operatively with the insertion of small screws. Comminuted fractures are treated conservatively, though the treatment of severely comminuted and displaced fractures is controversial and includes excision of fragments and/or the radial head with or without the insertion of Silastic implants. Early mobilization of the elbow is important to reduce residual stiffness (Figure 6.24 A,B).

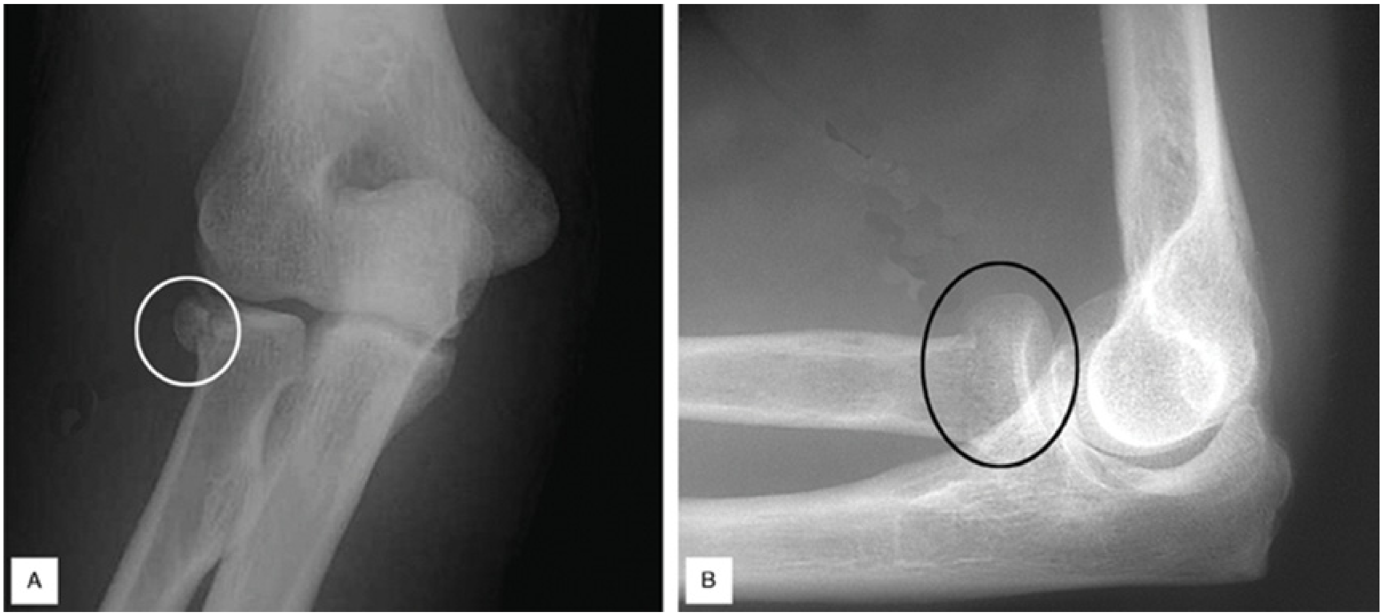


Figure 6.24 A,B Radial head fractures. Radiograph of a radial head fracture involving the articular surface (A). Radiograph of an impacted radial head fracture (B).

Humeral Fracture

Humeral shaft fractures are often the result of direct blows to the arm, motor vehicle crashes, or minor falls in the elderly. Physical exam reveals severe tenderness localized to the fracture area. Radial nerve injuries complicate up to 20% of humerus fractures, though median and ulnar nerves are rarely injured (Figure 6.25 A,B).

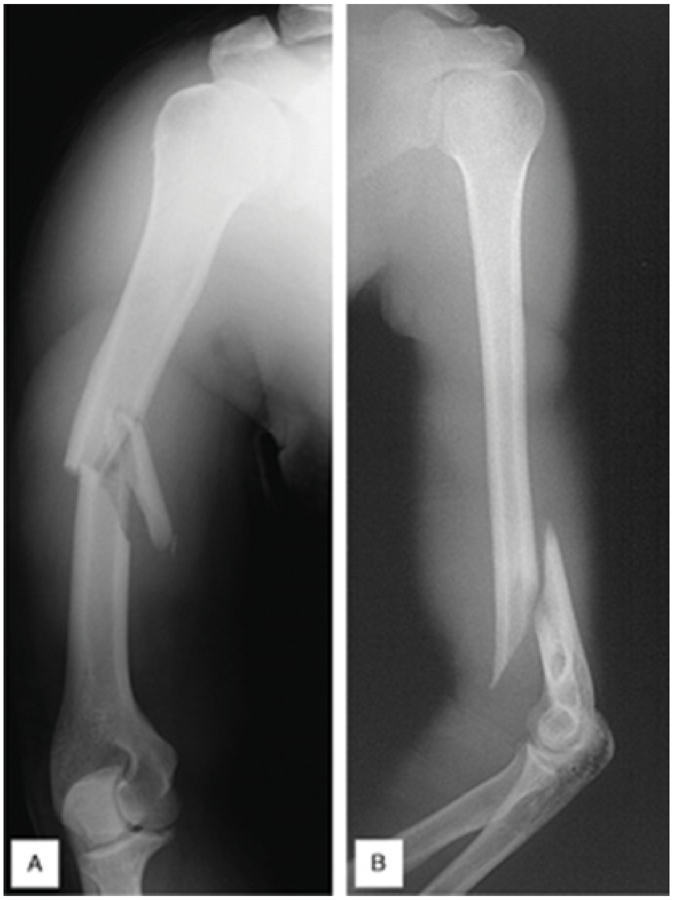


Figure 6.25 A,B X-rays of comminuted mid-shaft humerus fractures. This fracture is at high-risk for radial nerve injury (A). This injury is often associated with brachial artery injury (B).

Plain X-rays are most often diagnostic and conservative treatment is used for the majority of closed injuries. The sugar-tong splint and hanging cast are good techniques for immobilization. Open fractures, severely comminuted fractures, and fractures that are not adequately aligned by closed reduction are treated with open reduction.

Fractures of the humeral head most often occur in older patients after minor falls. Associated rotator cuff tears and fracture–dislocation of the humeral head are common complications. Initial management is with a sling and swathe, and the ultimate decision regarding open or closed treatment is based on the patient’s age, the number and displacement of fracture fragments, the quality of bone, and the presence of associated injuries.

Shoulder Dislocation

The shoulder is the most commonly dislocated joint. Shoulder dislocations can be classified as anterior, posterior, or inferior (luxatio erecta) (Figure 6.26 A,B).

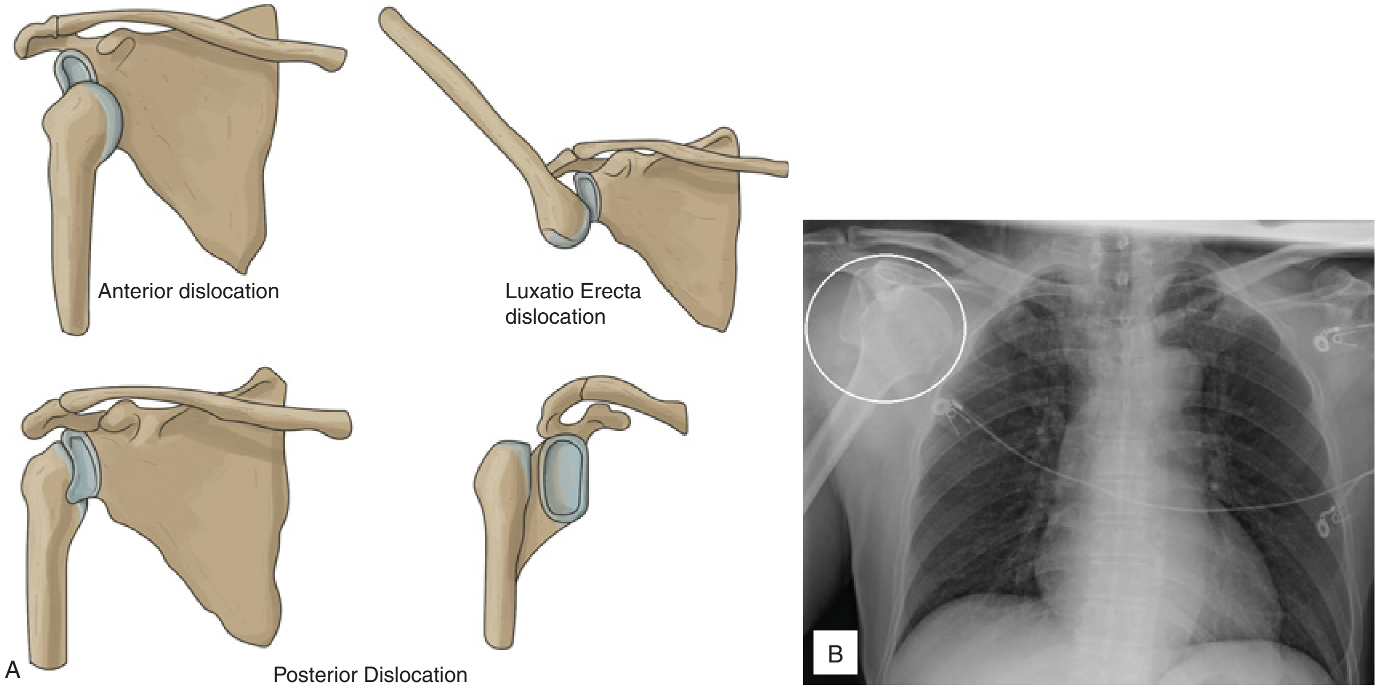


Figure 6.26 A.B Illustration of types of shoulder dislocations (A). Anteroposterior radiograph of an anterior shoulder dislocation with a large Hill–Sachs deformity (B).

Anterior dislocations constitute >90% of all shoulder dislocations. They are usually the result of a fall on an outstretched hand with the arm abducted, extended, and externally rotated. On examination, the arm is held in slight abduction and external rotation. The humeral head is palpable anteriorly, and a slight hollow is noticed in the shoulder laterally. Axillary nerve injury complicates shoulder dislocation in up to 10% of cases.

Standard X-ray includes anteroposterior and lateral views and either a transscapular Y view or an axillary view. X-ray may reveal a compression fracture in the humeral head termed a Hill–Sachs deformity. In addition, a small anteroinferior glenoid rim fracture called a Bankart lesion may be seen. Recurrent dislocation is common, especially with concomitant rotator cuff tears.

Multiple techniques that use traction, leverage, or a combination can be used to reduce this injury, including traction–countertraction, external rotation, the Stimson technique, scapular rotation, and the Hippocratic technique. Closed reduction is successful in the majority of cases, though operative repair is used in irreducible cases, unstable joints, large glenoid rim fractures, >5–10 mm of displacement of avulsed greater or lesser tuberosity fractures, and intrathoracic dislocations.

Posterior dislocations are rare injuries, comprising about 5% of all dislocations. They can be difficult to diagnose, and up to 50% are thought to be initially misdiagnosed. The injury occurs with an axial load on an adducted internally rotated and forward flexed arm, direct blow to the shoulder, or severe muscular contractions as from a seizure or electrical injury. The arm is usually internally rotated on exam, and the patient is unable to elevate the arm above 90 degrees. The anteroposterior radiograph may look nearly normal, and thus the transscapular Y view or the axillary view is often necessary to exclude the diagnosis. There are four important radiographic findings associated with posterior shoulder dislocation: the "light bulb" sign (rotation of the trochanters into an anteroposterior plane leaving the humeral head with the appearance of a light bulb), the deep sulcus sign (>6 mm distance between the humeral head and the glenoid rim), the "trough" sign (compression fracture of the humeral head resulting in two vertical parallel lines), and the rim or ellipse sign (loss of the usual elliptical overlap of the humeral head and the glenoid rim). Not all signs are present in a single patient, but the presence of any of these signs suggests a posterior dislocation. Reduction is accomplished by slow in-line traction, usually with general anesthesia, but many posterior dislocations require open reduction (Figure 6.26 C, Figure 6.26 D).

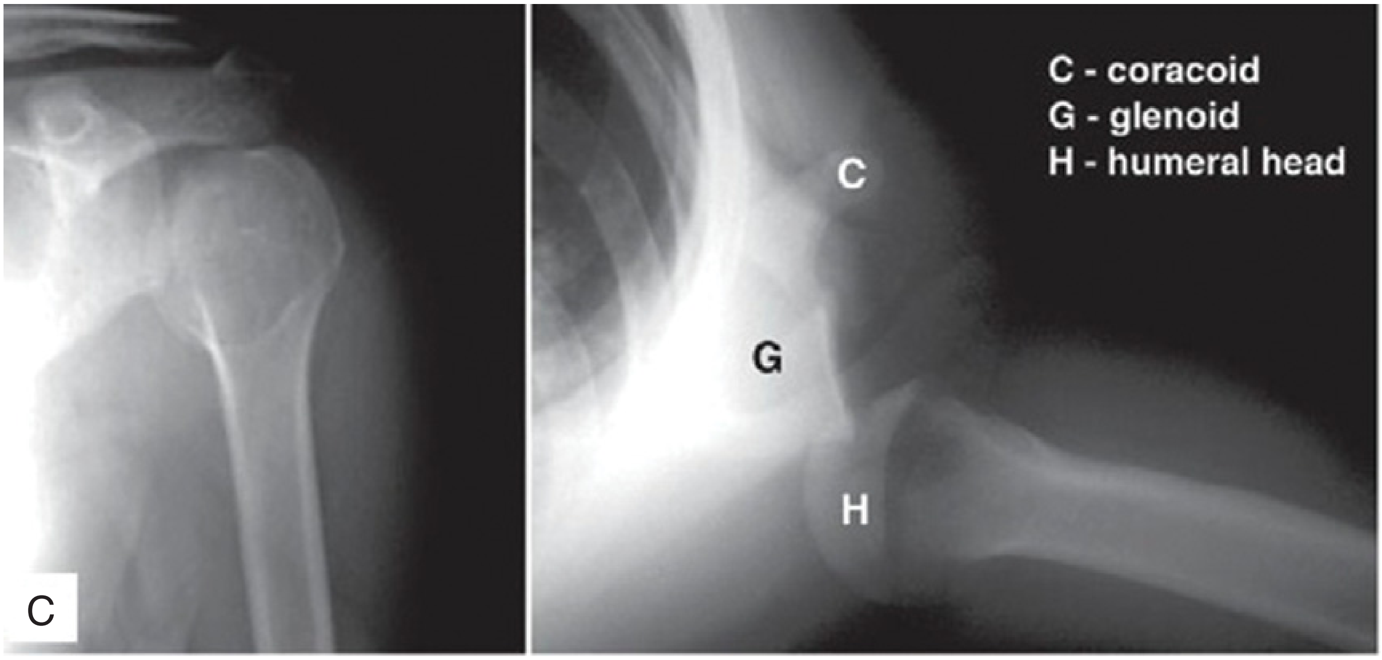


Figure 6.26 C Anteroposterior view of a posterior dislocation (left side) and axillary view of the same patient (right side).

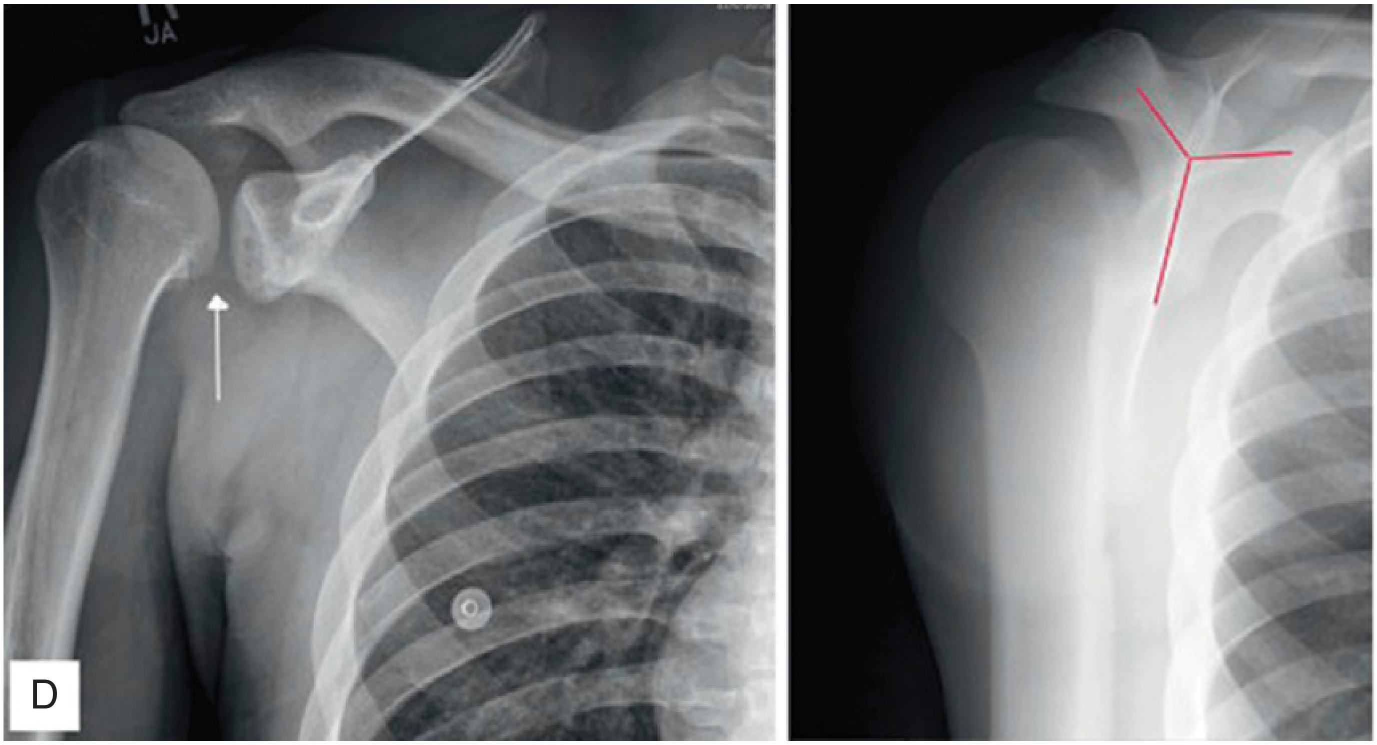


Figure 6.26 D Posterior dislocation showing loss of the usual elliptical overlap of the humeral head and the glenoid rim (left) and scapular-Y view showing the humeral head lying posterior to the scapula (right).

Inferior dislocation, also known as luxatio erecta, is a very rare dislocation forming <1% of all shoulder dislocations. The injury occurs with forced abduction of the arm, and the patient presents with a fully abducted arm with the elbow flexed and the forearm on or behind the head. Neurovascular compromise is common because these structures are inferior to the joint. Plain X-rays easily demonstrate the dislocation, and closed reduction is usually successful with a two-stage procedure. First, the dislocation is rotated downward with in-line traction and converted into a simple anterior dislocation.

Then reduction proceeds with reduction of the anterior dislocation. In a minority of cases, interposition of soft tissues makes closed reduction impossible and open reduction is required (Figure 6.26 E).

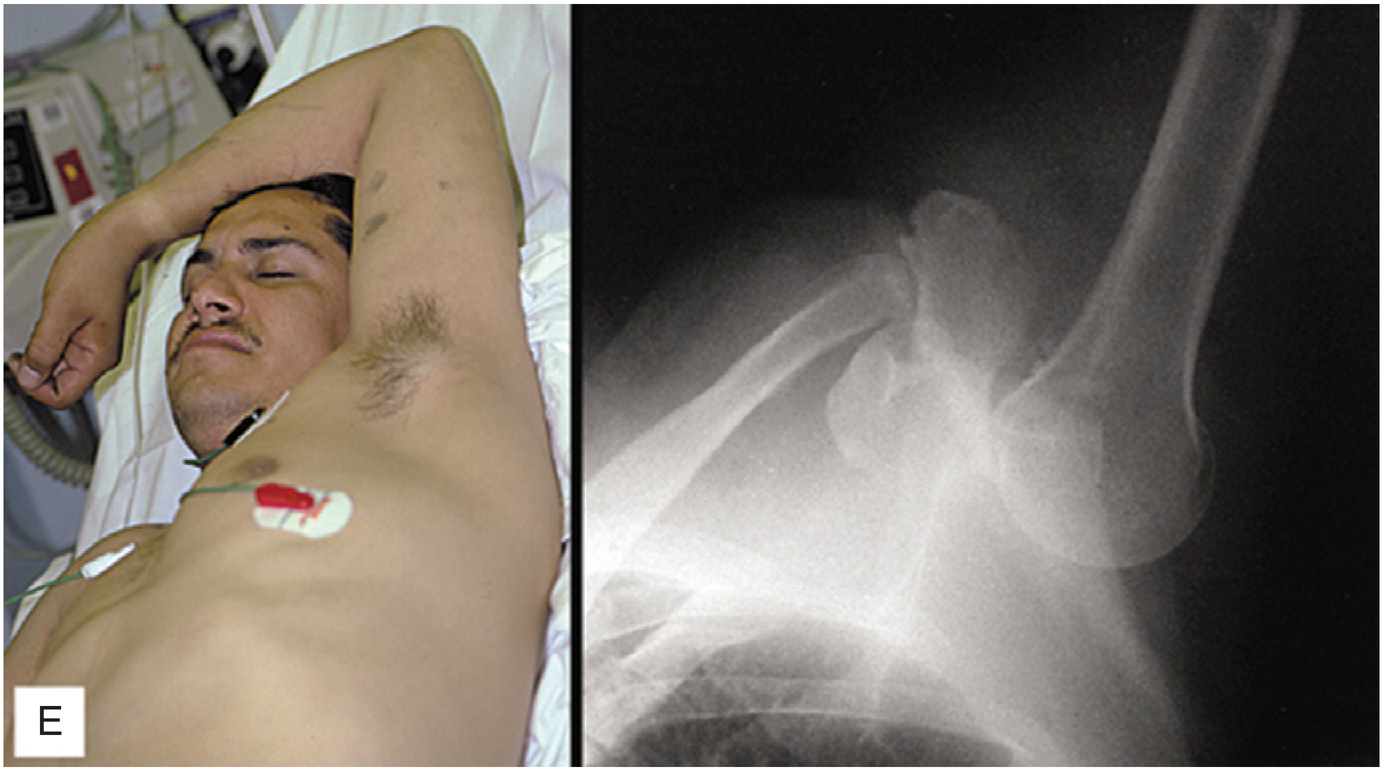


Figure 6.26 E Photograph of a patient with a luxatio erecta dislocation (left) and corresponding radiograph (right).

Open shoulder dislocation is rare but invariably results in severe disruption of the brachial plexus and vascular supply to the arm because the skin is the last structure to tear.

Clavicle Fracture

Clavicle fractures are common and can occur from a direct blow to the clavicle or from a fall on outstretched hand. Localized tenderness is found on examination, and radiography easily delineates the fracture. Complications are unusual but can include a host of serious injuries, including pneumothorax, subclavian vessel injury, tracheal injury, pacemaker malfunction, and thoracic outlet syndrome with brachial plexus injury (Figure 6.27 A,B).

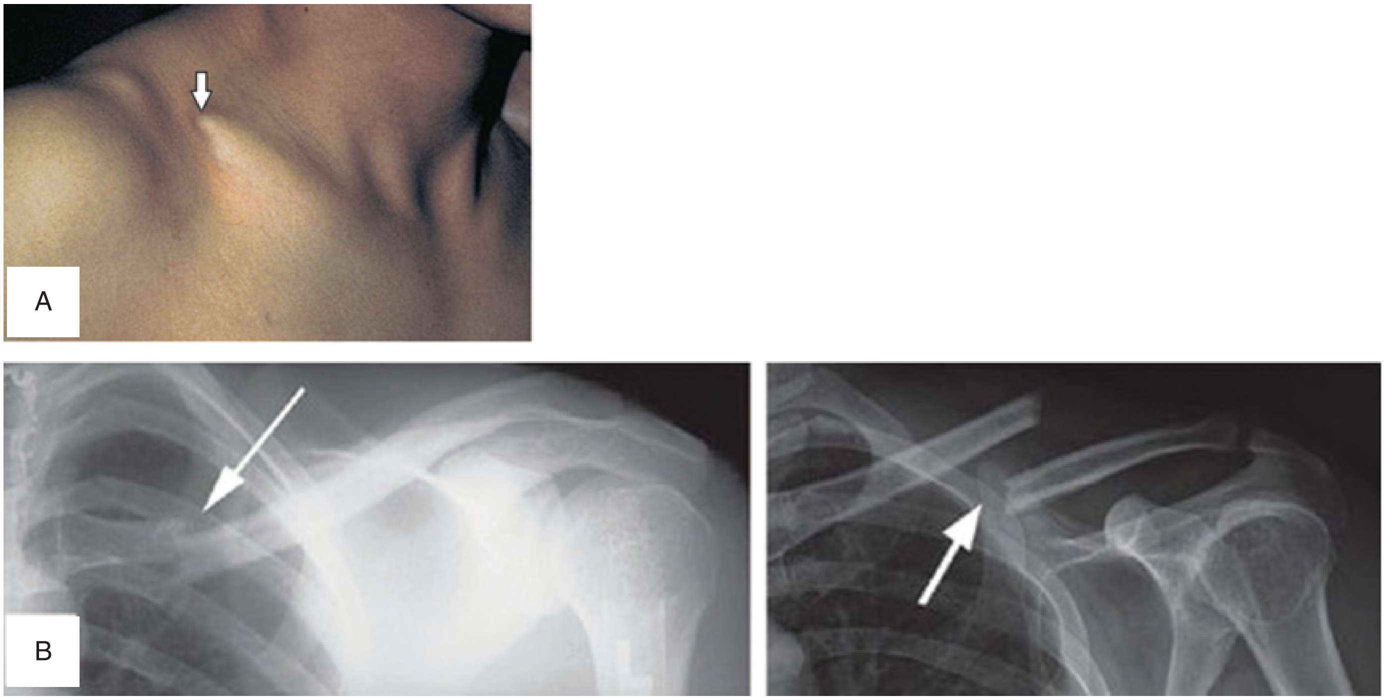


Figure 6.27 A,B Photograph of skin tenting seen with a displaced clavicle fracture (A). Clavicular fractures. Slightly displaced medial clavicle fracture on plain radiography (left). Mid-shaft clavicle fracture with significant displacement (right; B) These types of fracture are sometimes associated with subclavian vascular injuries.

Most clavicle fractures can be treated conservatively with a sling. Figure-of-eight bandages are no longer recommended. Open reduction is usually not necessary and is reserved for patients with open fractures, severe skin tenting, irreducible fractures with soft tissue interposition, unstable fractures, associated acromioclavicular dislocation, associated brachial plexus injury, or nonunion.

Sternoclavicular Dislocation

The sternoclavicular joint is the articulation of the medial aspect of the clavicle and the manubrium portion of the sternum. It is a "ball and socket" joint, and the dislocation may occur in any direction. The injury is rare, accounting for 1.5% of all dislocations, and is usually caused by high-energy mechanisms such as motor vehicle crashes or contact sports (Figure 6.28 A,B).

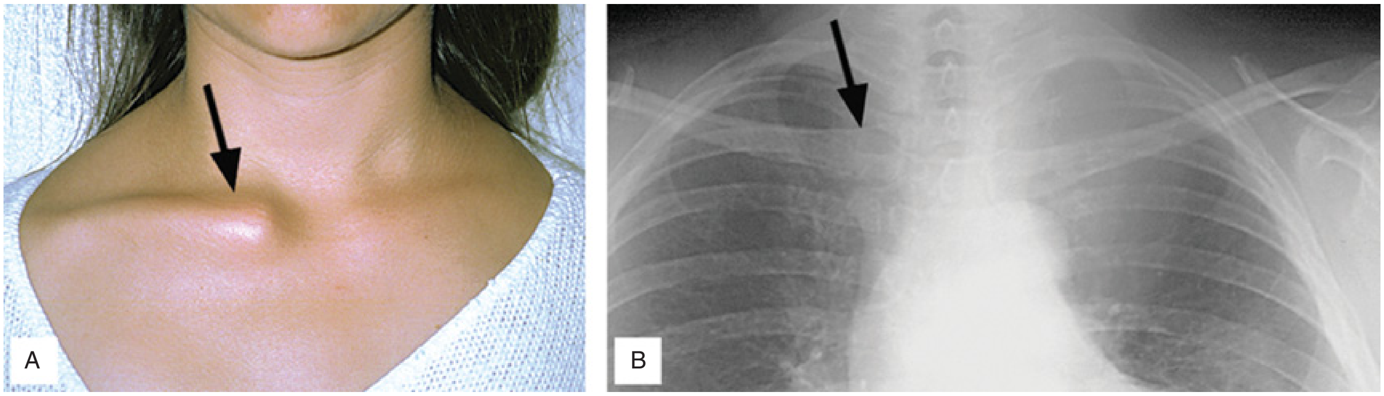


Figure 6.28 A,B Photograph of a woman with a right-sided anterior sternoclavicular dislocation (A). The chest radiograph shows asymmetry of the clavicles with respect to the sternum, with the right sternoclavicular joint in an abnormal position (arrow; B).

The injuries are classified as follows:

1. First degree: incomplete injury/stretching of the capsule
2. Second degree: mild subluxation
3. Third degree: complete dislocation

The majority of these dislocations are anterior (>90%). The less commonly seen posterior dislocation may be associated with life-threatening tracheal compression and airway compromise, vascular injury, and brachial plexus injury. First- and second-degree injuries are treated conservatively, but third-degree dislocation may require emergent reduction if the airway is compressed. Reduction is accomplished by having the patient lie supine with the arm abducted while traction is applied to the arm by an assistant. A towel clamp may be used to lift the proximal clavicle anteriorly if necessary. Reductions are unstable and often need surgical fixation.

Scapula Fracture

The scapula is integral to the normal function of the shoulder and is rarely injured, given its protection by thick surrounding musculature. Scapula fractures can be classified as follows:

- Body fracture
- Acromion fracture
- Scapula neck fracture
- Glenoid fracture
- Coracoid fracture

Body fractures are the most serious and comprise about 1% of all fractures. Mechanisms of injury include direct trauma, motor vehicle crashes, sports injuries, falls, and crush injuries. Examination reveals tenderness over the body of the scapula. Associated injuries are common, given the high energy required to fracture the scapula, and they need to be excluded. These injuries can include rib fractures, pneumothorax, hemothorax, pulmonary contusion, clavicle fracture, subclavian vessel injury, spine fracture, and skull fracture (Figure 6.29 A,B).

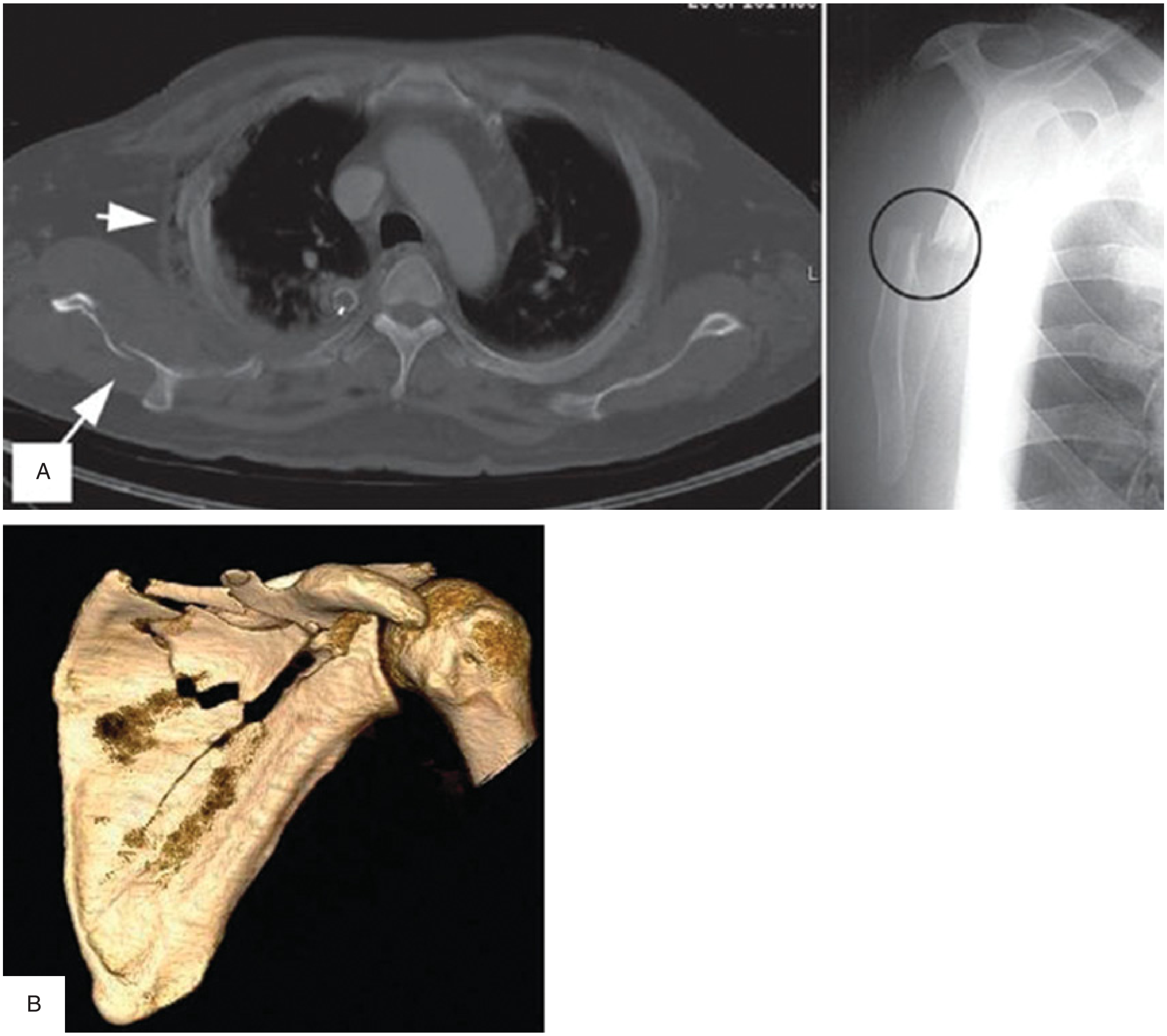


Figure 6.29 A,B Scapula fractures. CT scan of the chest showing a scapula fracture (large arrow) and rib fractures (small arrow) with a hemothorax (left; A). Scapular view radiograph illustrating a mid-body fracture with displacement (right). CT scan with 3-D reconstruction of comminuted fracture of the scapula (B).

Anteroposterior and transscapular radiographic views are usually sufficient to delineate the injury. In general, these fractures are managed conservatively with sling and swathe, though some authors prefer operative therapy.

Pelvic Fractures

Pelvic fractures pose two major challenges for emergency physicians and trauma surgeons. First, there is a high incidence of associated intra-abdominal injuries (about 28% of severe pelvic fractures). The clinical examination may be difficult, and hollow viscus injuries, which occur in about 13% of all severe fractures, may be missed. Second, these fractures can bleed profusely, and the bleeding is difficult to control.

A common classification of the pelvic fractures is based on the mechanism of injury and geography of the fracture, as follows:

Type A: Stable fractures, including isolated rami and iliac wing fractures, or pubic symphysis diastasis less than 2.5 cm

Type B: Partially unstable fractures (rotationally unstable, vertically stable)

- B1: Pubic symphysis diastasis more than 2.5 cm and widening of sacroiliac joints (open book fractures), caused by external hemipelvis rotation forces
- B2: Pubic symphysis overriding, caused by internal hemipelvis rotation forces

Type C: Disruption of the sacroiliac joint due to vertical shear forces. Unstable fractures (rotationally and vertically), often associated with severe bleeding

C1:Unilateral
C2:Bilateral
C3:Involving the acetabulum(Figure 6.30 A–D)

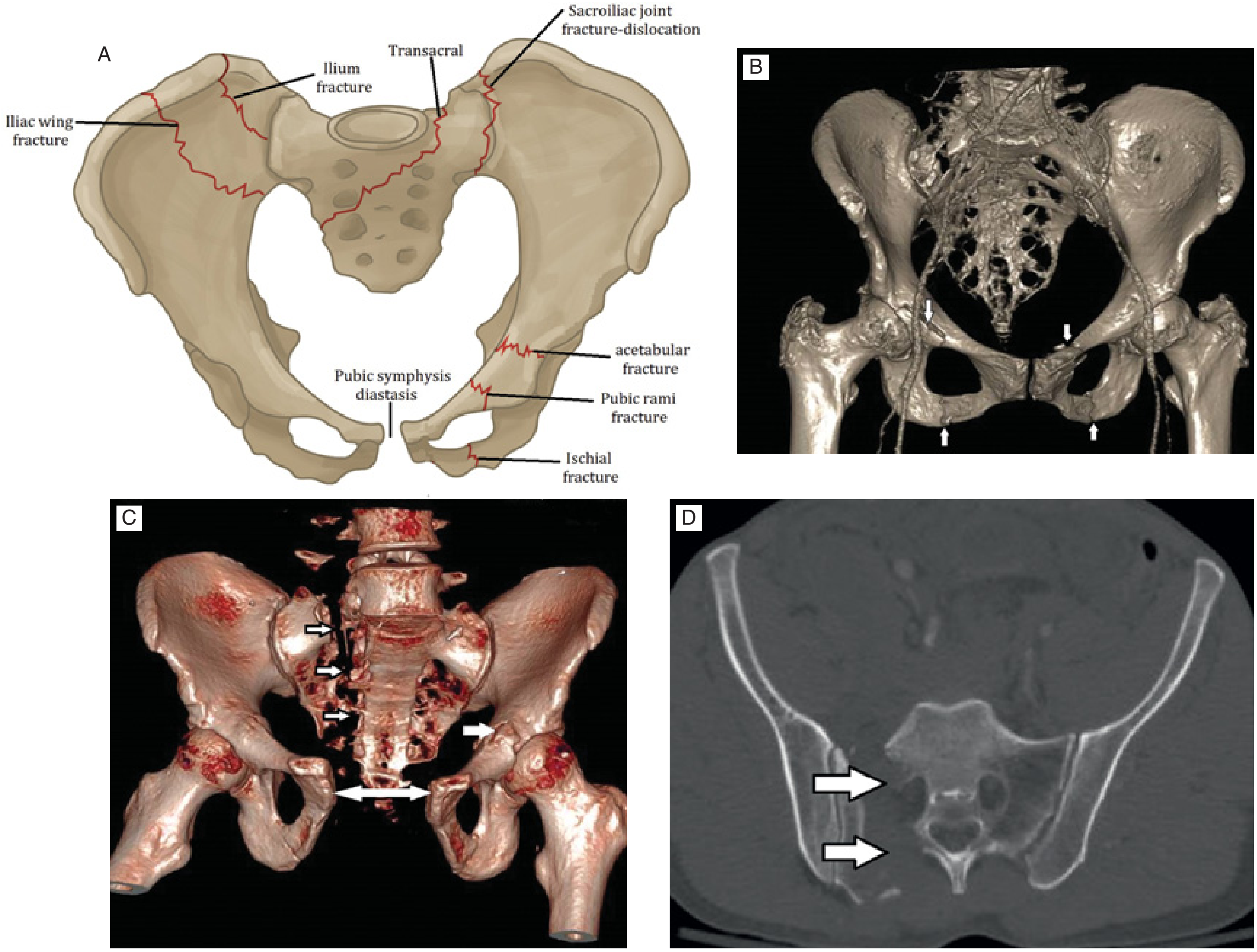


Figure 6.30 A–D Illustration of the different patterns of pelvic fractures (A). Pelvic X-ray showing bilateral pubic and ischial rami fractures resulting in a "butterfly" fragment. This injury is often associated with significant bleeding or rupture of the bladder (B). Pelvic CT scan showing unstable fractures with severe pubis symphysis diastasis, left acetabular fracture, and right sacroiliac joint disruption. This type of fracture is always associated with severe bleeding (C). CT scan shows fracture of the sacral bone with severe displacement. It is often associated with severe bleeding from the presacral venous plexus or the iliac vessel (D).

Clinical Examination

The abdominal examination is often difficult, because of the pain and abdominal wall hematoma associated with the fracture. The patient may be evaluated for pelvic instability by gentle compression over both iliac wings, although a false negative exam is common. This is a painful maneuver and should not be repeated by other physicians for confirmation or education. The clinical evaluation should include a rectal exam to rule out any rectal tears. In addition, the prostate should be assessed for a high-riding position, which is indicative of posterior rupture of the urethra. The meatus of the urethra should be examined for any gross blood. A urethral catheter should be inserted without using any force. In the presence of any resistance, the procedure should be abandoned and a retrograde urethrogram should be performed. In the appropriate cases, a vaginal examination should be done to evaluate for vaginal tears (Figure 6.31 A,B).

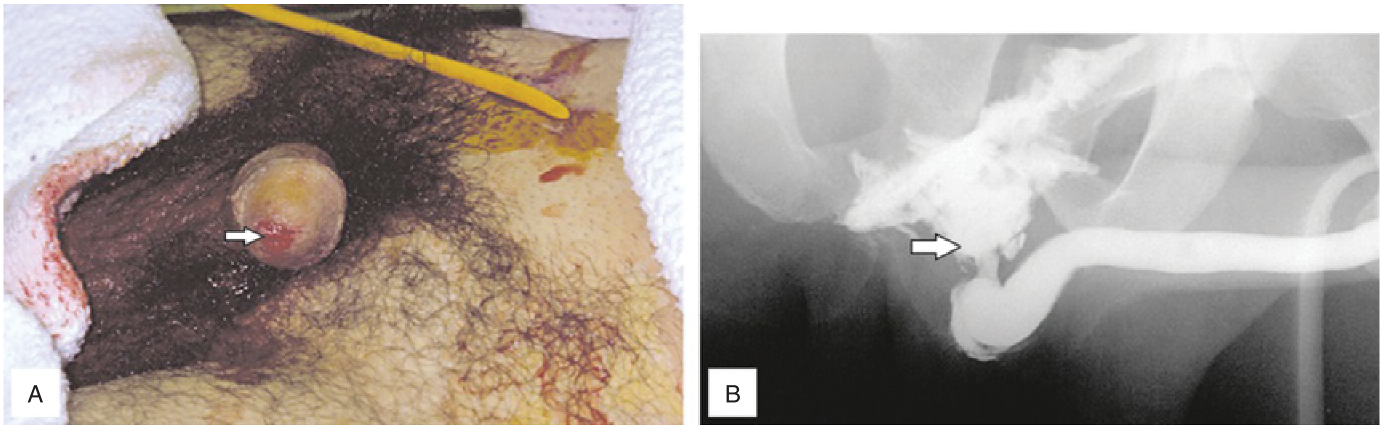


Figure 6.31 A,B Photograph of blood at the urethral meatus following pelvic fracture (A). Retrograde urethrogram shows injury to the urethra (B).

Investigations

An anteroposterior portable pelvic X-ray is indicated in order to assess the type and severity of the fracture and the suitability of applying a pelvic binder. A trauma ultrasound (FAST) should be routinely performed to identify any significant intraperitoneal bleeding. Retroperitoneal hematomas are usually missed by FAST. A diagnostic peritoneal aspirate (DPA) should be considered in the hemodynamically unstable patient with a negative FAST exam, who cannot safely be transported to the CT scan suite. The most valuable investigation is an abdominal and pelvic CT scan with intravenous contrast. It provides reliable information about intraperitoneal injuries, the type and severity of pelvic fracture, and can help in identifying those patients who may benefit from early angioembolization. Extravasation of contrast or a large hematoma are indications of significant bleeding and angiography should be considered.

Angiography with embolization of ongoing bleeding should be considered early, before the patient becomes hypotensive and coagulopathic. Parameters that are predictive of the need for angioembolization include pubic symphysis diastasis >2.5 to 3 cm, sacroiliac joint disruption, older age, and female gender. In these cases, early angiography should be considered.

Management

Immobilization of the fracture reduces pain and bleeding and should be done early. Rolling of the patient should be avoided and instead perform a straight lift using many helpers. Commercially available pelvic binders or sheet wrapping are practical and effective ways of pelvic fracture reduction and immobilization of open book fractures (large pubis symphysis diastasis). When placing a pelvic binder, the device should be centered over the greater trochanters. The duration of pelvic binder should be closely monitored as patients are at risk for pressure ulcers and compartment syndrome (Figure 6.32 A–E).

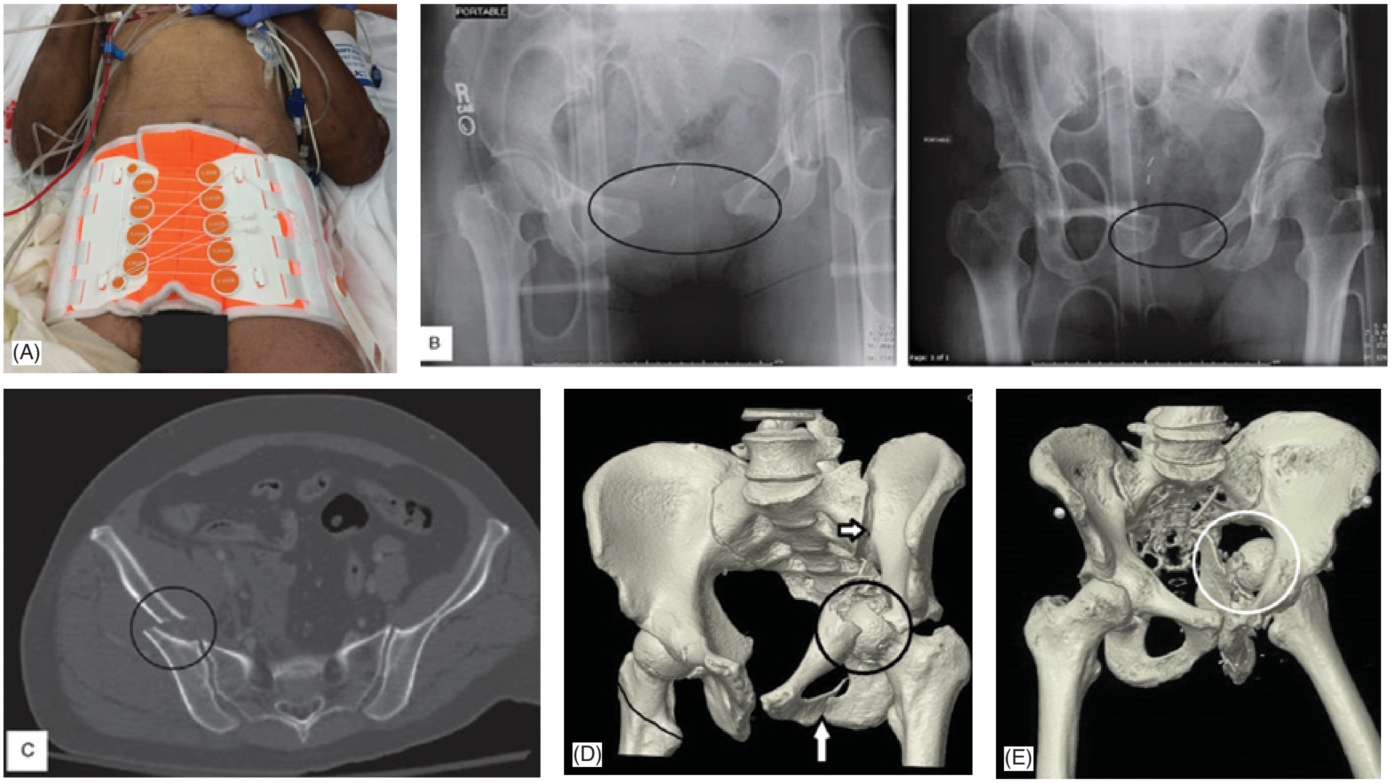


Figure 6.32 A–E Patient with open book fracture and a pelvic binder applied (A). Radiographs of the pelvis showing severe pubic symphysis diastasis before (left) and after (right) reduction and pelvic binder application (B). This type of immobilization is ideal for pubic symphysis diastasis but not other types of pelvic fractures. CT scan showing fracture of the right iliac wing (circle; C). CT 3-D reconstruction of a left acetabular impaction fracture (D). Application of a pelvic binder in these types of fractures is contraindicated because it worsens the fracture displacement (E).

Routine application of a pelvic binder is not recommended and can be counterproductive in some types of fractures, such as in iliac wing fractures, internal rotation fractures with pubic symphysis overriding, or acetabulum impaction fractures. In these cases, application of pelvic binder may worsen the fracture displacement. An anteroposterior pelvic X-ray can easily identify the cases that can benefit from a binder application.

In highly unstable fractures, external pelvic fixation performed by the orthopedic team should be considered. In the majority of pelvic fractures, bleeding can safely be managed with appropriate immobilization and blood transfusions. A small number of cases may need angioembolization. Patients with contrast extravasation on CT scan are candidates for angioembolization (Figure 6.33 A–C).

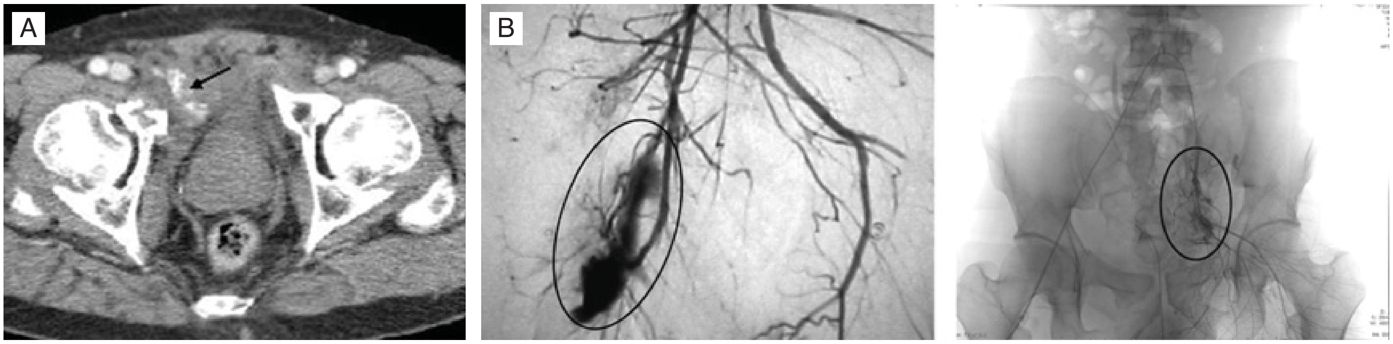


Figure 6.33 A–C CT scan showing significant contrast extravasation (arrow) from a pelvic fracture (A). This patient is a strong candidate for angioembolization. Angiograms of patients with complex pelvic fracture showing severe active bleeding (B, C).

In rare occasions when the patient is too unstable for angiography or angioembolization fails, surgical intervention with damage control of the pelvic fracture bleeding can be lifesaving (Figure 6.34 A,B).

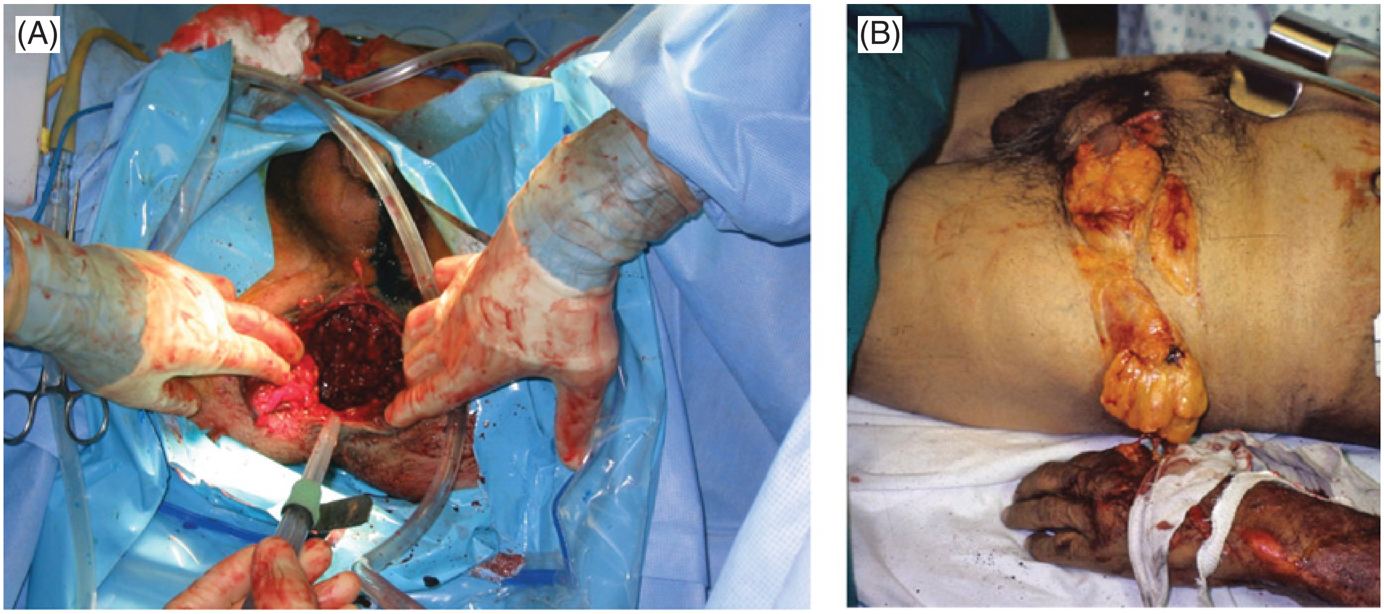


Figure 6.34 A,B Photographs of open pelvic fractures. Patient with open pelvic fracture in the perineum (A). Patients following motorcycle collision with open pelvic fracture and intestinal evisceration (B). These patients require emergency operation for the management of associated abdominal injuries, bleeding control, and washout.

The management of these patients is a multidisciplinary team effort, including trauma surgeons, emergency physicians, orthopedic surgeons, interventional radiologists, and anesthesiologists.

All patients with complex pelvic fractures should be admitted to the intensive care unit for close monitoring and timely therapeutic interventions. The intra-abdominal pressure should be monitored closely because some of these patients may develop abdominal compartment syndrome, which requires immediate surgical decompression. Definitive internal fixation should be considered a few days later (usually 2–4 days after admission) when the bleeding and hematoma are stabilized.

Hip Dislocation

Hip dislocations occur from high-energy trauma such as motor vehicle collisions and are true orthopedic emergencies because of the risk of ischemic necrosis of the femoral head. Because many patients present with severe associated trauma, other injuries may take priority, but the hip dislocation should be addressed before other orthopedic concerns. Ninety percent of all hip dislocations are posterior, with only about 10% being anterior. Rarely seen are central dislocations in which there is a concomitant fracture in the floor of the acetabulum. Given the energy involved, a femoral head fracture may also be present, and X-rays should provide good views of the femoral head and neck. In addition, the sciatic nerve is at risk with posterior dislocations and the femoral nerve and vessels may be damaged with anterior dislocations; thus the affected lower extremity requires a careful neurovascular examination (Figure 6.35, Figure 6.36 A,B).

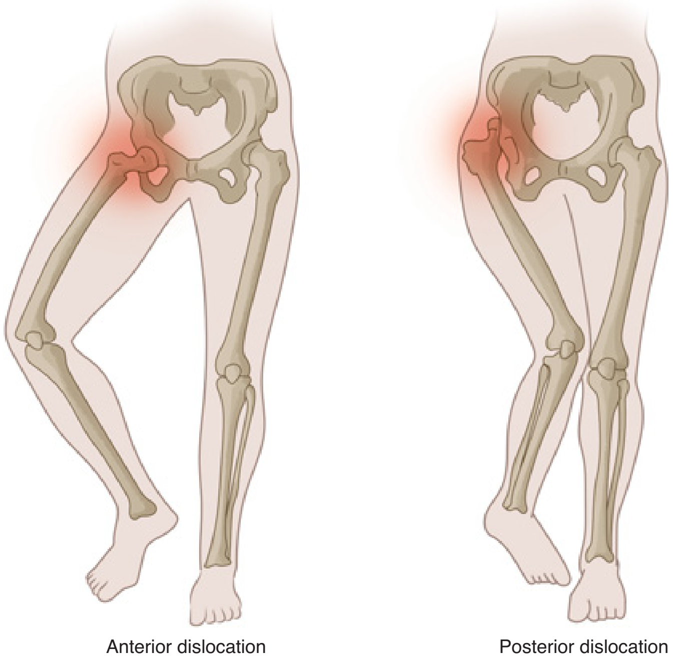


Figure 6.35 Illustration of the classic position of adduction, flexion, and internal rotation seen in a posterior hip dislocation, and extension and external rotation seen in anterior hip dislocation.

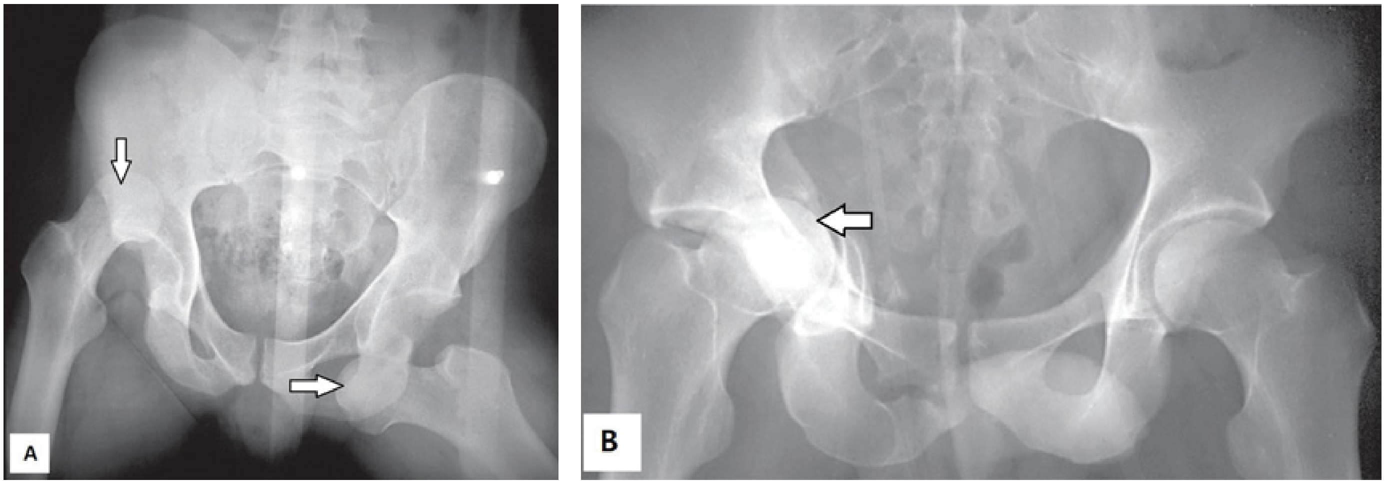


Figure 6.36 A,B Anteroposterior pelvis radiograph reveals both a posterior (right hip) and an anterior hip dislocation (left hip) occurring simultaneously in a patient involved in a motor vehicle collision (A). Anteroposterior pelvis radiograph showing a right central hip dislocation with an acetabular fracture (B).

Early closed reduction is paramount, as the femoral head has a limited blood supply. The average rate of avascular necrosis is 20%, and the risk rises to 50% in reductions performed 12 hours or more after the injury. Reduction of posterior hip dislocation can usually be accomplished using the Allis or Stimson techniques with appropriate deep sedation, though some patients will require operative reduction (Figure 6.37 A,B).

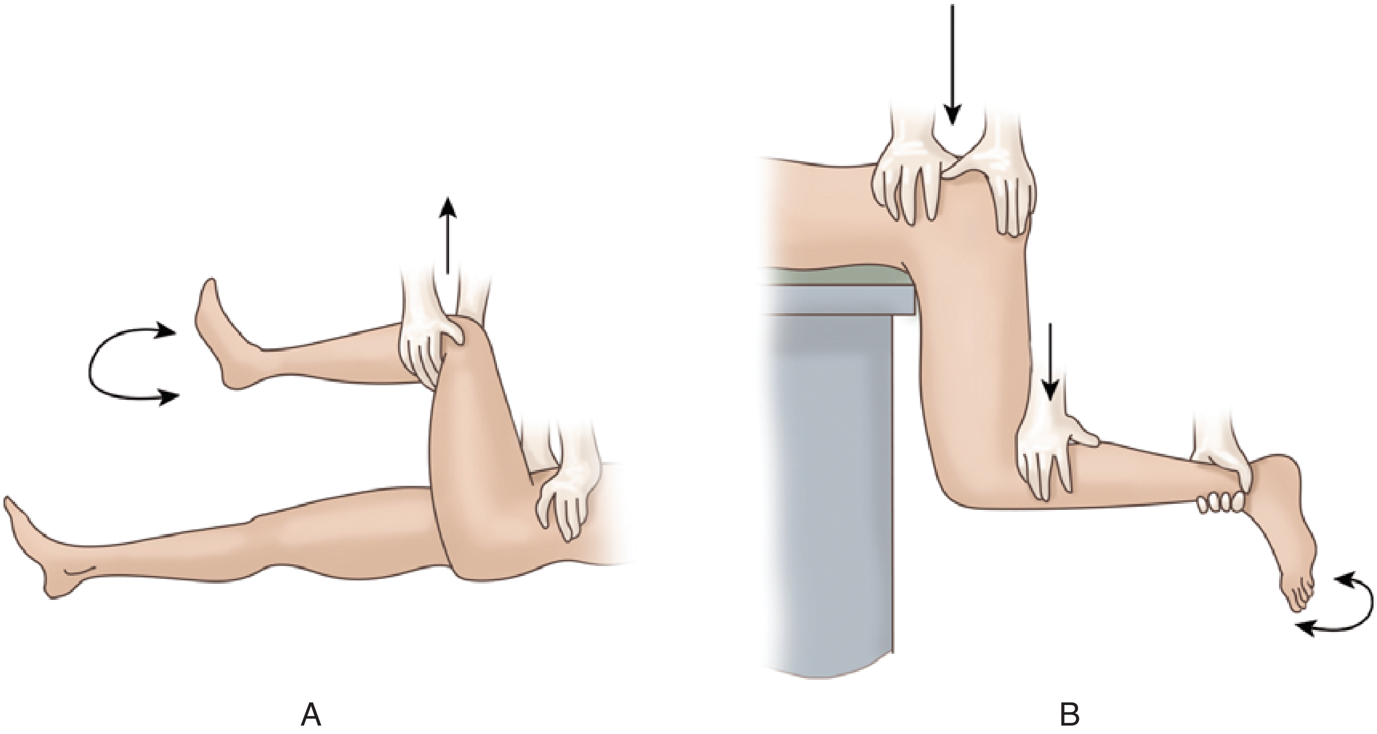


Figure 6.37 A,B Illustration of Allis closed reduction technique used for posterior dislocations (A). Illustration of Stimson closed reduction technique used for posterior dislocation (B).

Hip Fractures

Hip fractures are commonly seen in the elderly, who are prone to osteoporosis and minor falls. Fractures in patients younger than 50 usually require high-energy mechanisms or a pathological process affecting the hip. Most patients complain of pain in the medial thigh or groin, and there is significant discomfort with internal or external rotation. In addition, the affected leg is often shortened and externally rotated, though neurovascular status is usually intact.

Hip fractures can be classified as femoral head fractures, neck fractures, intertrochanteric fractures, and subtrochanteric fractures (Figure 6.38 A,B).

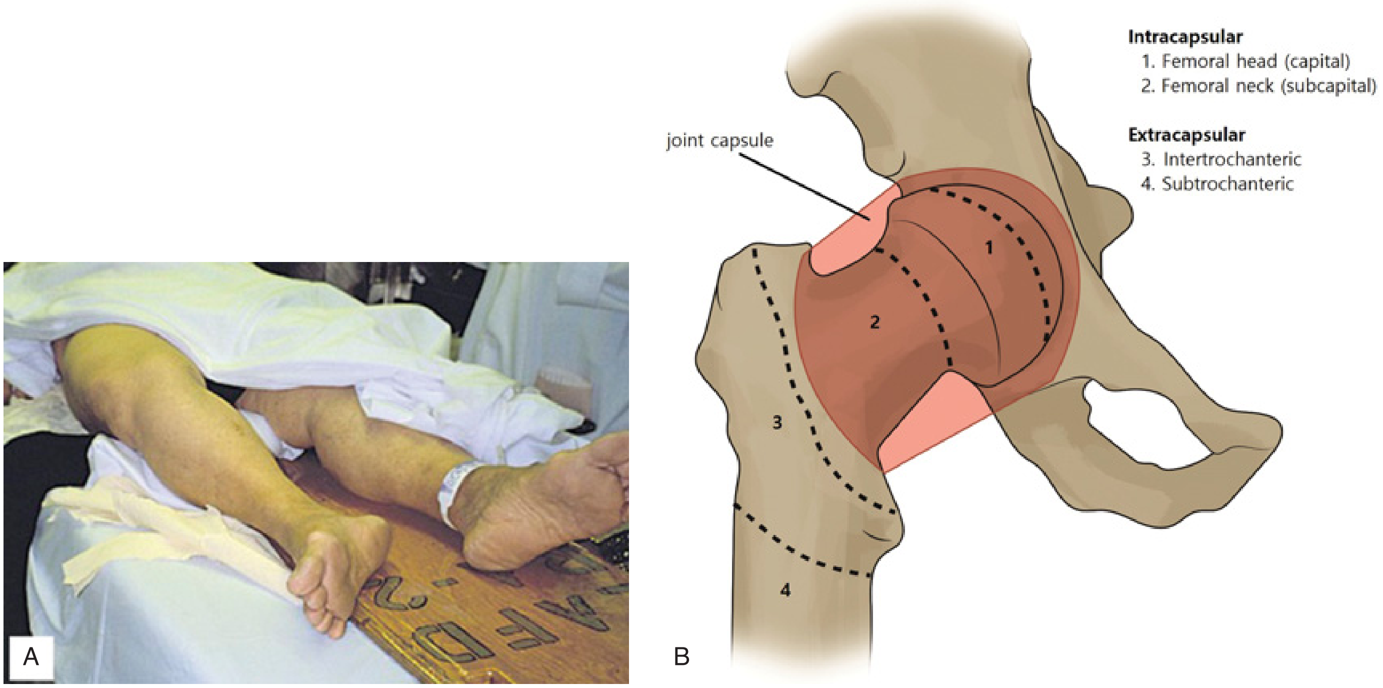


Figure 6.38 A,B Shortened and externally rotated right leg after hip fracture (A). Illustration of anatomic types of hip fracture (B).

Standard radiographic evaluation includes an anteroposterior pelvis X-ray, along with coned views of the hip and a lateral view of the hip. On the anteroposterior pelvis view, it is important to examine the trabeculae carefully and to look for a disruption of Shenton's line. Shenton's line is an imaginary curved line along the inferior border of the superior pubic ramus and along the inferomedial border of the neck of femur. This line should be continuous. Interruption of the line indicates fracture of the neck of the femur (Figure 6.38C, Figure 6.38 D–F).

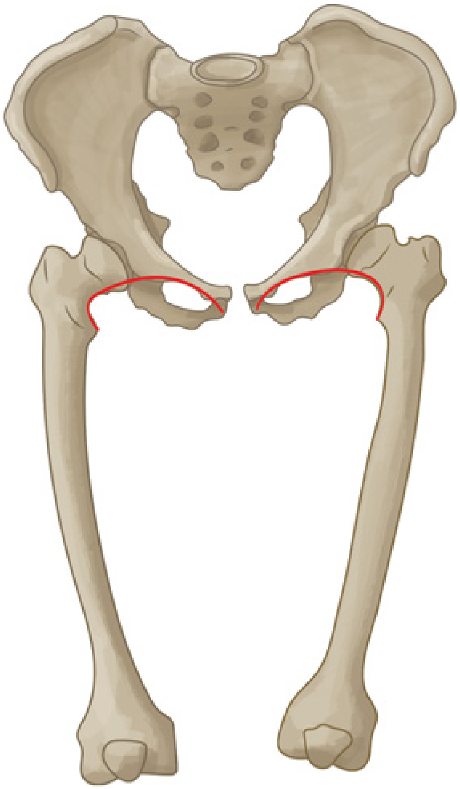


Figure 6.38C Illustration of Shenton's line. Hip radiograph of a femoral neck fracture.

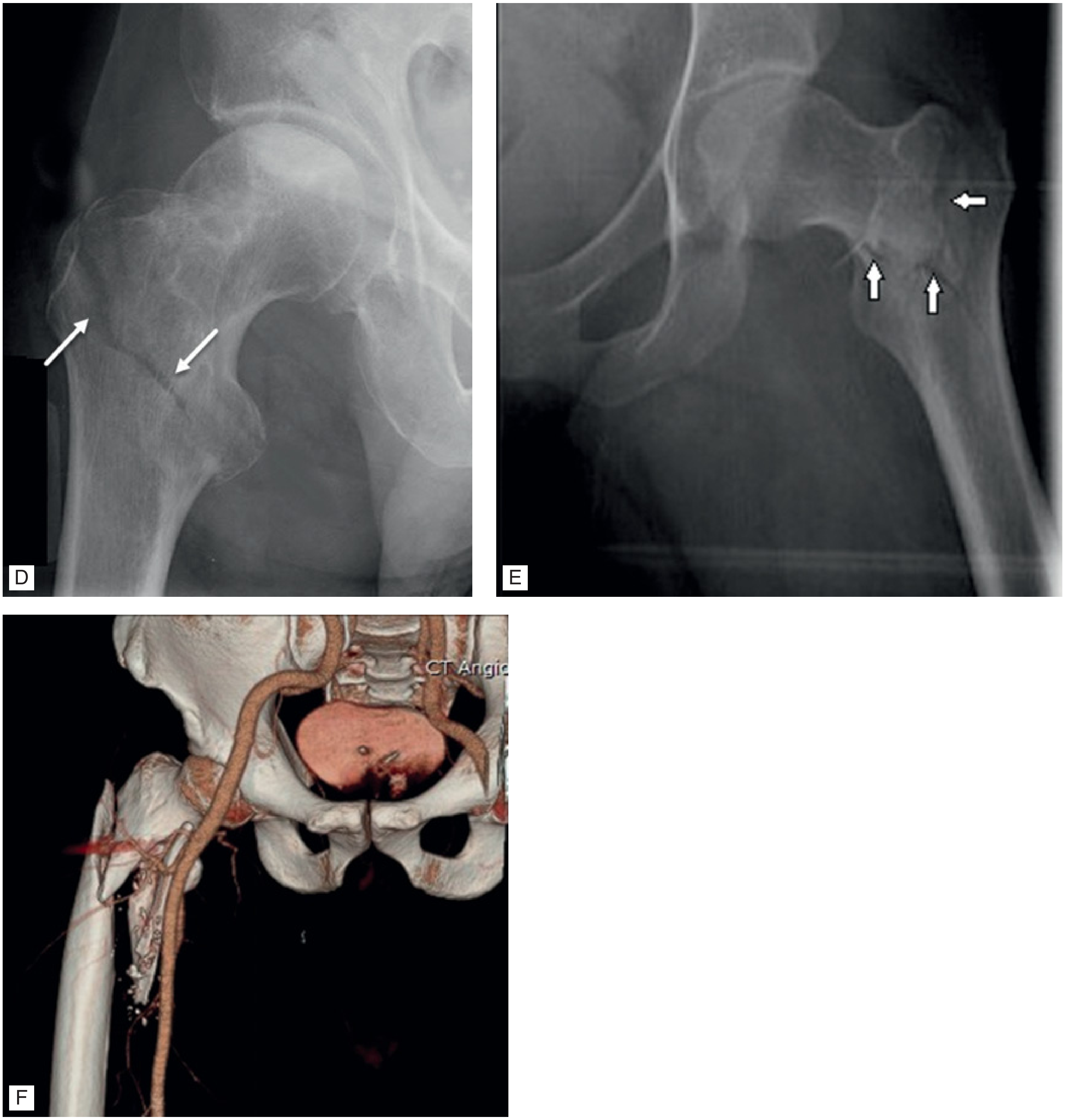


Figure 6.38 D–F Hip radiograph of a right intertrochanteric hip fracture (D). Left intertrochanteric hip fracture (E). Communited right transtrochanteric fracture following a traffic collision. CTA shows normal femoral artery (F).

Detection of minor fractures can be difficult, and plain X-rays can appear normal; thus CT or MRI is indicated in patients with normal plain X-rays but persistent hip pain or inability to bear weight on the affected leg.

Femoral head and neck fractures are intracapsular fractures and have a limited blood supply, making avascular necrosis a serious concern. In contrast, both intertrochanteric and subtrochanteric fractures have an excellent blood supply. Prosthetic hip replacement or external fixation is used to manage most hip fractures. Early mobilization of elderly patients avoids numerous complications associated with prolonged immobilization, such as pulmonary embolus, pneumonia, and sepsis. Femoral nerve block can provide excellent analgesia for these fractures in the emergency department.

Children differ from older adults in respect to this injury. Pediatric bones and periosteum are much stronger, and thus more severe trauma is required to produce hip fractures in this population. Comminution is not seen as often, and the periosteum often remains intact, thus limiting displacement. However, the presence of the epiphyseal plate predisposes to late growth complications, and the incidence of avascular necrosis is higher. In addition, children have a better tolerance to bedrest and immobilization, making these treatment options a possibility for some injuries.

Femoral Shaft Fracture

The femur is the longest and strongest bone in the body, and thus fractures often require high-energy mechanisms such as major falls, motor vehicle collisions, or gunshot wounds. Physical examination reveals gross laxity of the femur, thigh swelling, and severe pain.

Significant blood loss can occur, and each fractured femur can easily lose three units of blood. Consequently, femur fractures are an important cause of hemorrhagic shock in the trauma victim. A careful physical examination is necessary to exclude neurovascular injury or compartment syndrome that may be present. Plain X-rays usually reveal the fracture clearly but should not delay the resuscitation of a critical patient, as they rarely will alter acute management. In the acute setting, apply gentle traction to reduce displaced fractures, and splint the limb to maintain anatomic positioning and minimize soft tissue injury and blood loss. In the presence of a diminished peripheral pulse or in proximity gunshot wounds, a CTA should be performed. Orthopedic consultation is necessary, and most mid-shaft fractures will be treated operatively with an intramedullary rod (Figure 6.39 A–C).

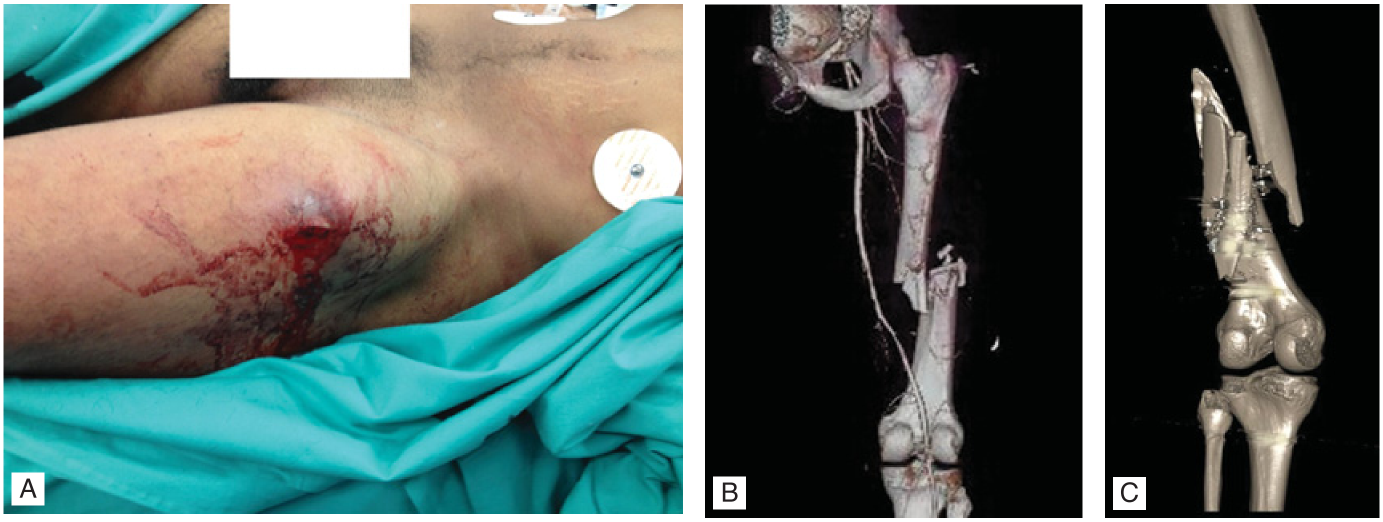


Figure 6.39 A–C Gunshot wound to the left thigh with a large hematoma (A) and CTA shows a fracture of the femoral shaft (B). The femoral artery is intact. CT scan of patient with a high-velocity gunshot wound to the femur (C). A CTA should always be performed to evaluate for vascular injuries.

Patellar Fracture

Patellar fractures account for approximately 1% of skeletal fractures, and most result from direct trauma to the knee or resisted forceful extension of the knee. On examination, there is often point tenderness over the patella, with significant swelling and ecchymosis. A large hemarthrosis may occur with patellar fractures, and joint aspiration may be necessary for pain relief. The quadriceps extensor mechanism may be affected and thus should be tested for integrity by asking the patient to extend the knee against gravity and then against resistance. Radiographic assessment should include anteroposterior, lateral, and skyline X-rays, although small undisplaced fractures can still be difficult to detect, and a bipartite patella can be a confusing normal variant. Three types of fractures are commonly seen: transverse, longitudinal, and stellate (Figure 6.40).

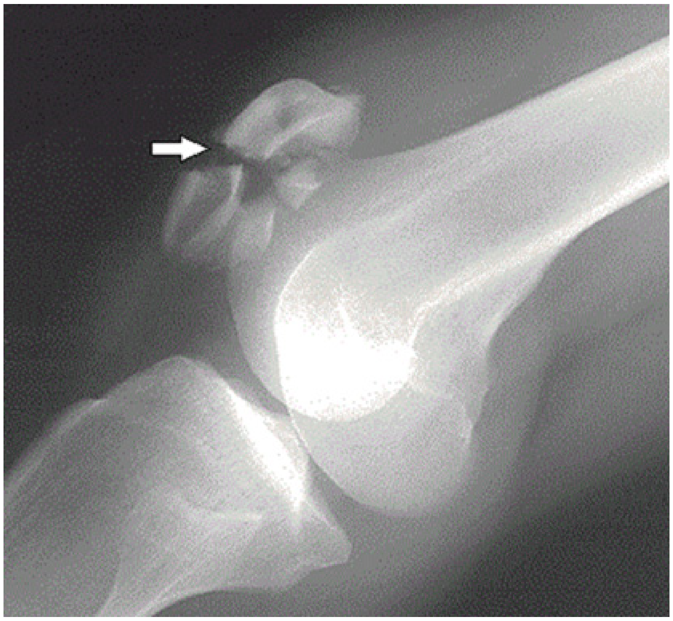


Figure 6.40 X-ray shows a transverse fracture through the body of the patella.

Most patellar fractures can be successfully treated by conservative therapy with cylindrical casting or a bulky Jones dressing for smaller fractures. Operative repair is done for open fractures, widely displaced fractures, severe articular disruption, osteochondral fractures, and longitudinal fractures.

Tibial Plateau Fracture

Tibial plateau fractures are often the result of direct shear forces. With most car bumpers being 20 inches high, the tibial plateau is at high risk in auto-versus-pedestrian accidents. Swelling, hemarthrosis, point tenderness, and pain with any motion of the knee make weight-bearing impossible. Ligamentous injury may coexist and thus should be sought out on the clinical examination. Standard anteroposterior and lateral radiographs with oblique views will demonstrate the fracture in most cases, but occasionally CT scan may be needed to further define the injury. The medial plateau is stronger, and thus fractures usually involve the lateral plateau. Generally, tibial plateau fractures are of two varieties: split and/or depressed. Split fractures tend to occur in younger patients with stronger bone, and depressed fractures more often occur in the elderly patient with osteoporosis (Figure 6.41 A–C).

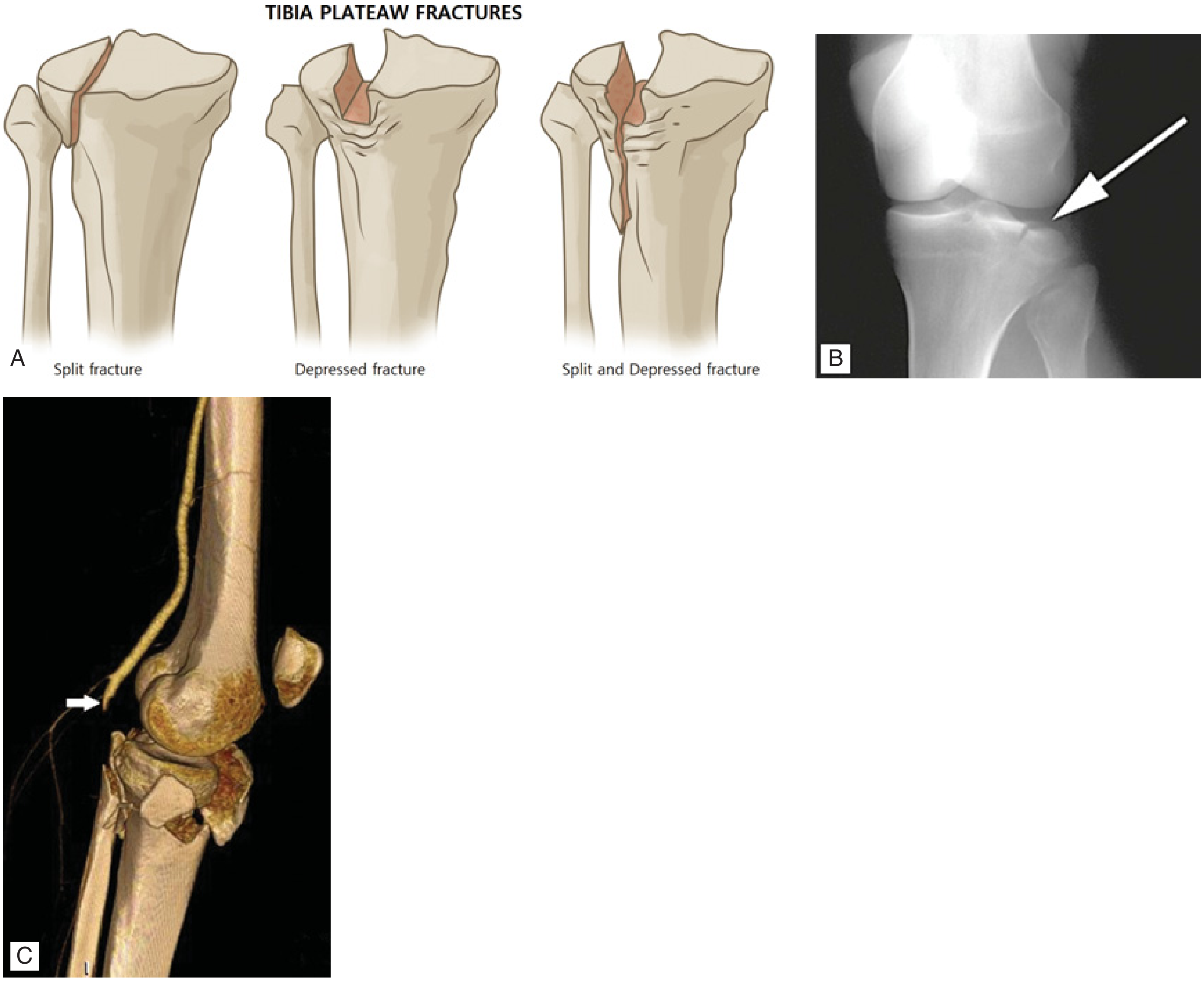


Figure 6.41 A–C Illustration of types of tibial plateau fractures (A). This anteroposterior view of the knee reveals a lateral split plateau fracture (arrow; B). Auto versus pedestrian injury with clinical fracture of the proximal tibia and absent peripheral pulses. CT angio shows fracture of the tibial plateau and head of fibula and occlusion of the popliteal artery (arrow; C).

As tibial plateau fractures involve the articular surface of a major joint, they are at high risk for persistent pain and arthritis and thus should be managed by an orthopedic surgeon. In the past, the fractures have generally been casted, but because of the residual stiffness often associated with casting, surgical intervention and early mobilization are increasingly being used to achieve anatomic alignment and avoid complications.

Knee Dislocation

Knee dislocation is rare but extremely important to recognize, as missed coexistent popliteal artery injury can lead to limb loss. This injury requires a high-energy mechanism and is often seen in the context of multiple trauma. Knee dislocation is classified according to the position of the tibia in relation to the femur. There are five major types of dislocation:

- Anterior: Anterior dislocation is often caused by severe knee hyperextension.
- Posterior: Posterior dislocation occurs with anterior to posterior force to the proximal tibia, such as a dashboard type of injury or fall from a significant height on a flexed knee.
- Medial, lateral, or rotator: Medial, lateral, and rotator dislocations result from varus, valgus, or rotatory forces, respectively (Figure 6.42).

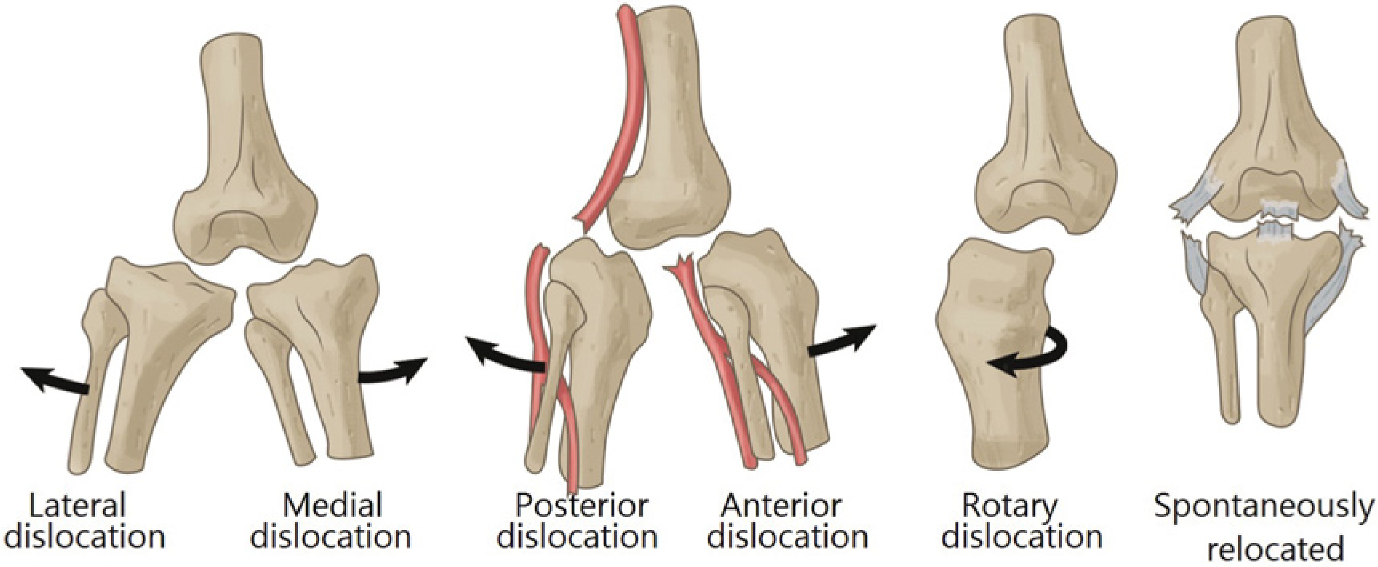


Figure 6.42 Illustration of types of knee dislocation.

Almost all dislocations are anterior or posterior, and both have a high incidence of popliteal artery injury. Physical exam of the affected limb will show gross deformity around the knee, with swelling and immobility. The finding of varus or valgus instability with the knee in full extension is suggestive of a complete ligamentous disruption and a spontaneously reduced knee dislocation (Figure 6.43 A–C).

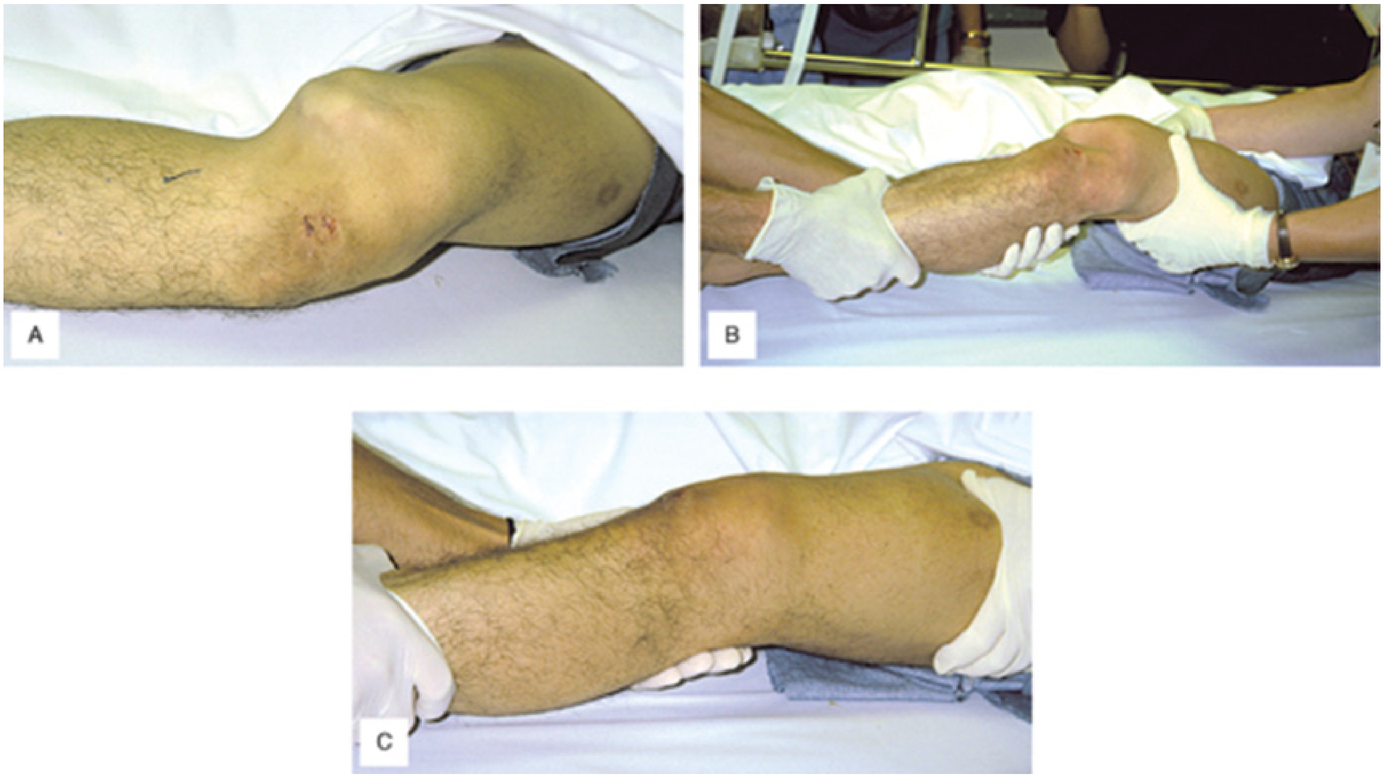


Figure 6.43 A–C Photograph of a lateral knee dislocation (A). Reduction of the dislocation (B). Postreduction showing knee in good position (C).

A careful vascular examination is essential, as popliteal artery injury occurs in 35–45% of all knee dislocations, and the presence of normal pulses does not rule out a significant vascular injury. All patients should be initially evaluated using the ABI and color flow doppler ultrasound. Patients with abnormal findings on these studies will need CTA or formal angiography (Figure 6.44 A,B)

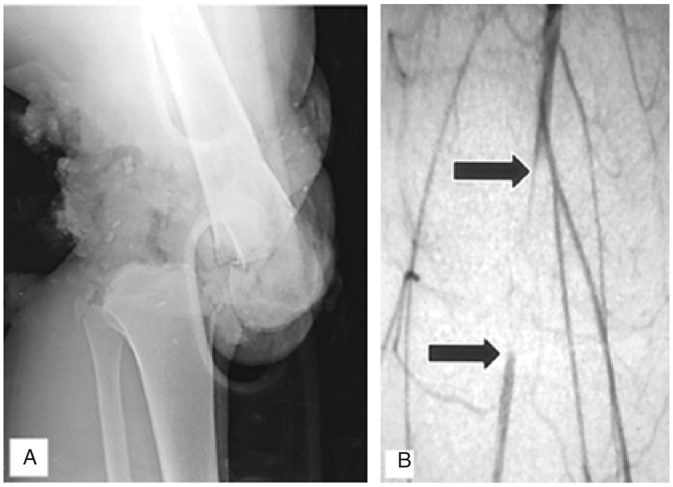


Figure 6.44 A,B X-ray of a posterior knee dislocation and distal femur fracture (A). The patient had no peripheral pulses. Angiogram shows popliteal artery injury (B).

Patients with a cold, pale, pulseless distal extremity should undergo vascular repair directly without angiography if the six-hour warm ischemia time limit is approaching. Coexistent peroneal nerve injury occurs in 25–35% of cases and manifests with decreased sensation at the first web-space with impaired dorsiflexion of the foot.

Emergency treatment consists of prompt reduction with gentle in-line traction. Definitive treatment includes identification and repair of the vascular injury. Limb loss occurs in about a third of all cases.

Maisonneuve Fracture Complex

The Maisonneuve fracture complex represents 5–7% of all ankle fractures and can be easily missed if the treating physician is not familiar with this injury pattern. The mechanism typically involves external rotation of the inverted or adducted foot. The complex includes a combination of proximal oblique fibular fracture, disruption of the tibiofibular ligament distally, and a medial malleolar fracture or deltoid ligament tear. In addition, the interosseous membrane may be torn.

Typically, the patient has severe ankle pain that often involves the entire lower leg. Careful examination reveals medial malleolar tenderness, and this fracture complex underscores the importance of noting coexistent tenderness at the proximal fibula. Plain radiographs reveal a medial malleolar fracture or widening of the medial mortise with an oblique proximal fibular fracture (Figure 6.45).

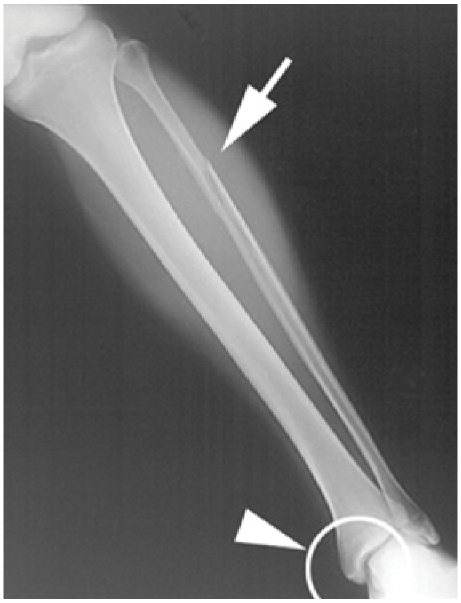


Figure 6.45 Plain radiograph showing widening of the medial ankle joint and a proximal fibular fracture.

Treatment is directed toward restoring integrity of the ankle mortise. Although some patients are treated conservatively with casting, most patients need operative repair.

Ankle Dislocation

Ankle joint dislocations are often secondary to sudden rotational forces, such as from sports injuries, falls, and motor vehicle accidents. Dislocations of the ankle are described according to the direction of displacement of the talus and foot in relation to the tibia and are most commonly lateral, although medial, posterior, and anterior dislocations are also seen. Dislocation without fracture is rare (Figure 6.46 A,B).

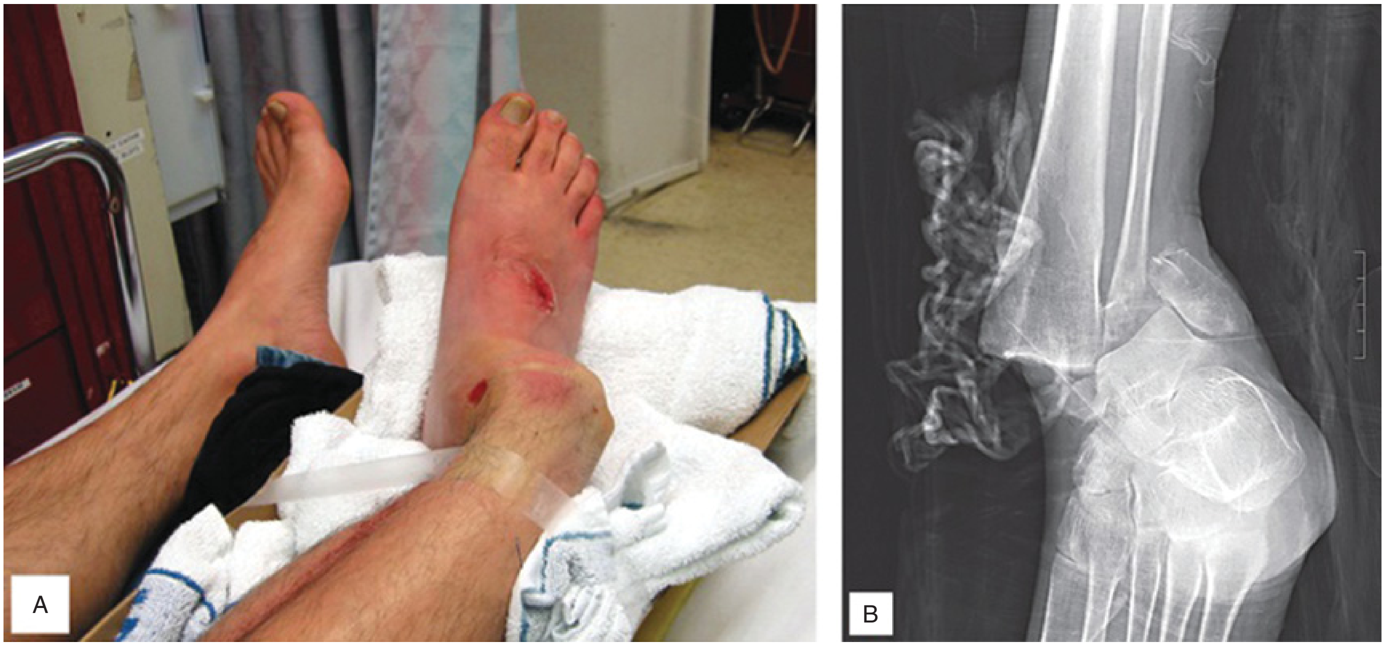


Figure 6.46 A,B Patient with a medial ankle dislocation following a motor vehicle collision (A). X-ray shows ankle dislocation with bimalleolar fracture (B).

Neurovascular status should be checked, although most often remains intact. Reduction is relatively straightforward and accomplished by flexing the knee to 90 degrees, stabilizing the lower leg, plantar flexing the foot, and pulling forward and reversing the direction of the dislocation. Gross ligamentous disruption with or without fracture is consistently present, and thus surgical stabilization is necessary in this injury.

Subtalar Dislocation

Subtalar or peritalar dislocation requires the disruption of both the talocalcaneal and talonavicular joints without affecting the tibiotalar joint. This uncommon injury is usually the result of severe torsional forces, such as in falls or motor vehicle collisions. Dislocations can be anterior or posterior, although medial and lateral are the most common. Obvious deformity is present, and the anteroposterior radiograph can be used to confirm the diagnosis (Figure 6.47 A–D).

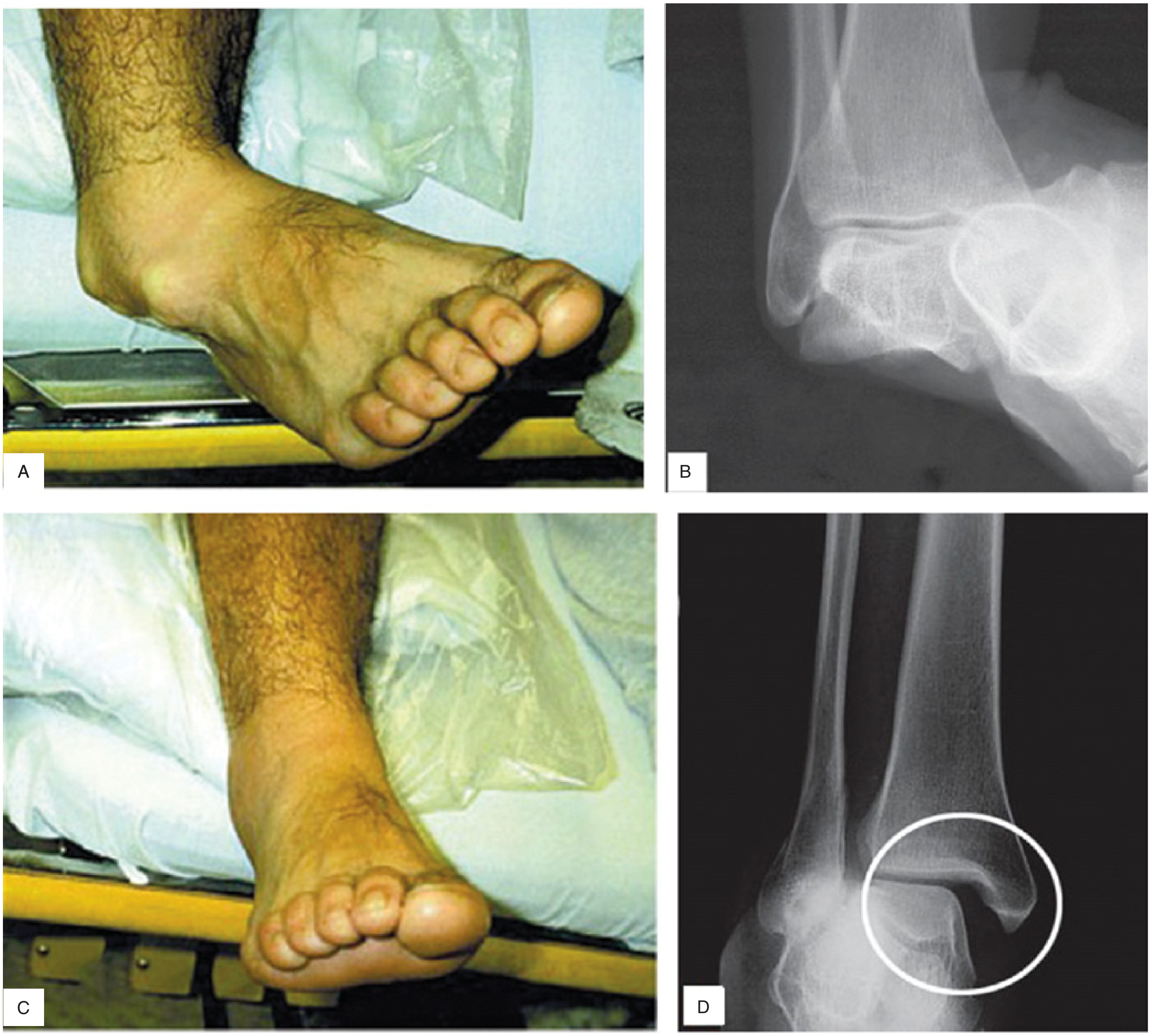


Figure 6.47 A–D Patient with a medial subtalar dislocation (A). X-ray shows medial subtalar dislocation (B). Same patient post reduction (C). Radiograph of a widened ankle mortise (circle) signifying disruption of the deltoid ligament (D).

Reduction should not be delayed and can usually be accomplished by in-line traction and reversal of the deformity. Most cases are managed conservatively with a below-knee cast with good results, although chronic limitation of motion at the subtalar joint may affect the gait.

Lisfranc Fracture

The tarsometatarsal joints are commonly called Lisfranc joints, and dislocation or fracture/dislocation injury to this area is termed Lisfranc injury. The joint consists of articulations between the bases of the first three metatarsals and their respective cuneiforms and the fourth and fifth metatarsal with the cuboid. These joints are normally held in place by strong ligaments, and thus this injury is most commonly seen with high-energy mechanisms such as motor vehicle accidents (Figure 6.48 A–C).

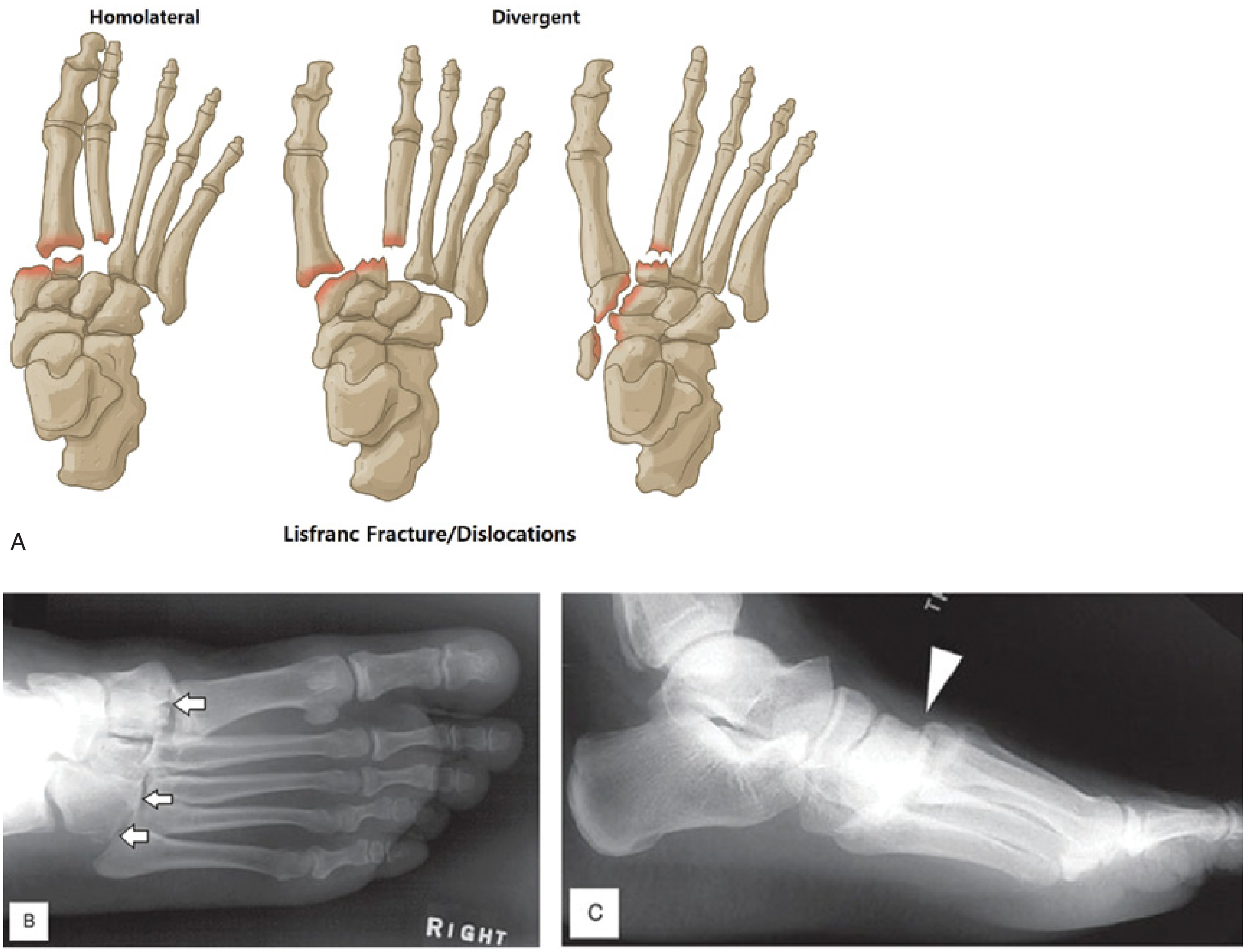


Figure 6.48 A–C Illustration of types of tarsometatarsal dislocations (A). Homolateral tarsometatarsal dislocation seen on the anteroposterior foot X-ray (B). Plain radiograph of divergent Lisfranc dislocation (C).

Because of the strong ligamentous attachments, associated fractures of the metatarsals are often seen. Usually the injury to the foot is clinically evident, with significant swelling and tenderness of the forefoot. Occasional vascular injury may occur in a branch of the dorsalis pedis artery, which forms the plantar arch. Radiographically, the fracture dislocation may be grossly evident or quite subtle. The first four metatarsals should align with their respective tarsal articulations along the medial edges. Disruption in this area or widening around the bases of the first three metatarsals is suggestive of an injury. Therapy of Lisfranc fractures usually involves closed reduction with internal fixation using percutaneous Kirschner wires followed by casting.

Metatarsal Base Fractures

When assessing fractures at the base of the fifth metatarsal, it is important to distinguish isolated tuberosity fractures from diaphyseal fractures, as the treatment and incidence of complications varies significantly. Avulsion fractures usually occur with sudden inversion of the plantar flexed foot. The insertion of the peroneus brevis has been implicated in these fractures by causing avulsion of the styloid process. Fortunately, these fractures usually heal well without complication. Treatment of these isolated tuberosity fractures ("dancer's fractures") will be determined by the degree of pain and discomfort present, as these fractures may be treated with a compressive dressing, stiff shoe, or a short walking cast (Figure 6.49 A,B).

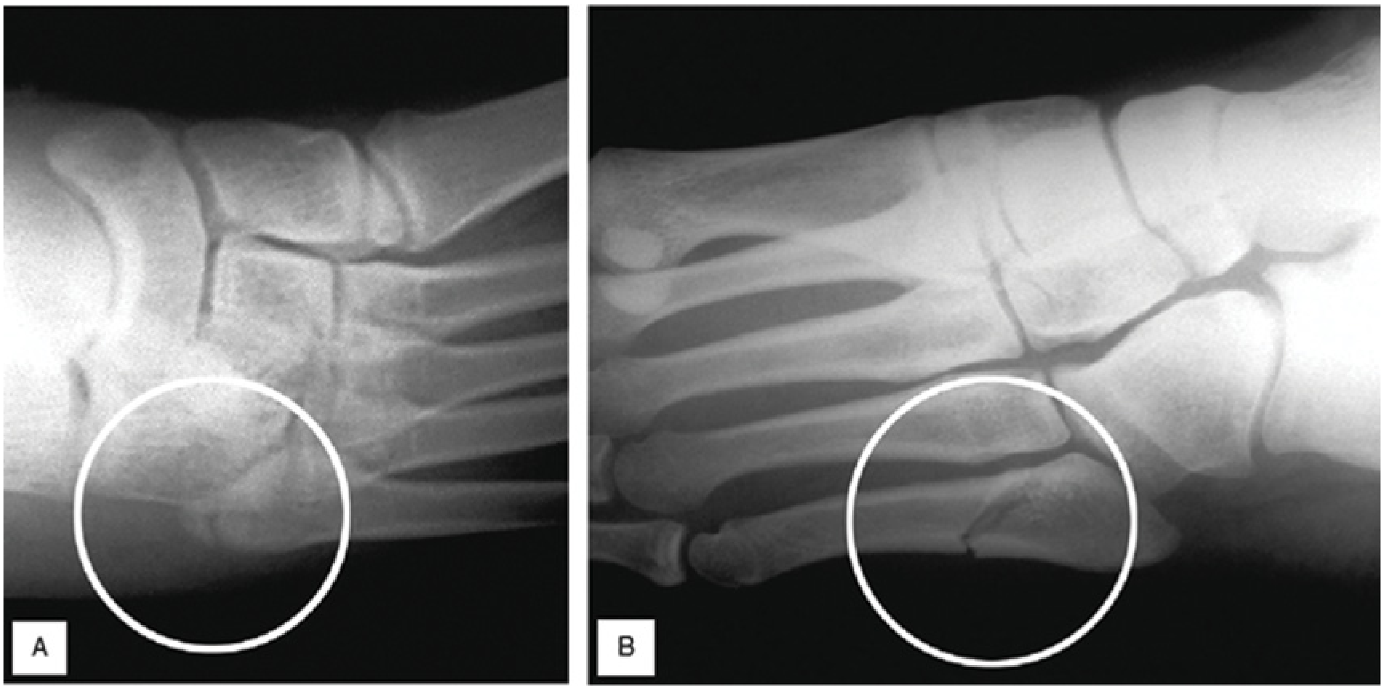


Figure 6.49 A,B X-ray of an avulsion fracture of the proximal fifth metatarsal (circle; A). X-ray of a diaphyseal fracture of the proximal fifth metatarsal (circle; B).

Diaphyseal fractures usually occur with running or jumping injuries, and transverse fractures within 15 mm of the proximal bone are often termed Jones fractures. Undisplaced fractures of this type are usually treated with casting and non-weight-bearing for 6–8 weeks, but may require longer immobilization or surgery. Displaced fractures are usually treated operatively. Complications of this diaphyseal fracture are common and include delayed union, nonunion, and recurrent fracture.

Calcaneal Fractures

The calcaneus is the largest bone in the foot and requires high energy, such as a major fall, for fracture to occur. Associated injuries are also common and are important to detect. These include bilateral calcaneal injuries, lower leg injury, and vertebral fractures. Typically, significant pain and deformity around the heel are noted, and weight-bearing is impossible. Compartment syndrome can complicate this injury and must be considered (Figure 6.50 A–C).

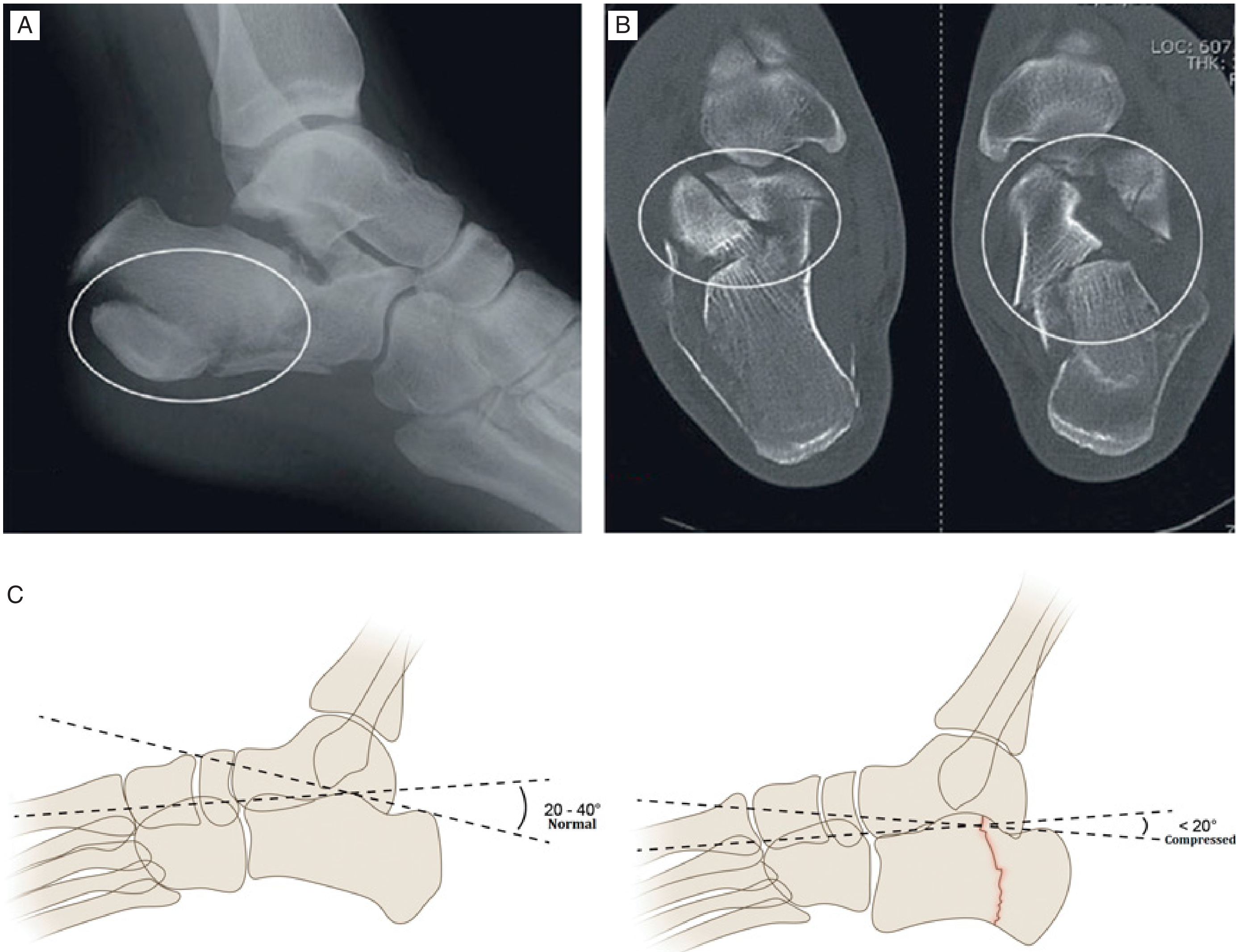


Figure 6.50 A–C X-ray of a comminuted fracture of the calcaneus involving the subtalar joint (A). CT scan of bilateral calcaneal fractures (B).Illustration of Bohler's angle. This angle is seen on the lateral view and is the angle between lines connecting the three highest points of the calcaneus (C).

Standard X-ray views include a lateral and anteroposterior view shooting down the foot and an axial calcaneal view down the posterior half of the calcaneus (Harris view).

Comminution is commonly seen, as the bone is cancellous in nature. For examining the radiographs, Bohler's angle can assist in determining if compression has also occurred. This angle is normally 20–40 degrees, and loss of this angle suggests compression of the calcaneus. However, Bohler's angle is not always abnormal, even with comminuted calcaneal fractures, and it is more useful in determining prognosis than in diagnosis. In addition, subtalar joint involvement is important to recognize, as many of these patients are treated operatively. In contrast, nondisplaced extraarticular fractures will often be treated with casting for 6–8 weeks. Despite optimal therapy, chronic pain and joint dysfunction are seen in 50% of patients.

Chapter

7

Spinal Injuries

Mark J. Spoonamore and Demetrios Demetriades

Introduction

In the US, approximately 10,000 spinal cord injuries yearly result in permanent disability. Most spinal cord injuries are caused by motor vehicle collisions (40%), violence (30%), falls (20%), and sporting accidents (6%). Although spinal fractures can occur in any age group, the peak incidence is in males from ages 18 to 25. Certain conditions predispose to spinal fracture, spinal cord injury, or dislocation: old age, rheumatoid arthritis, osteoporosis, and spinal stenosis.

About 90% of all spinal injuries due to blunt trauma are located at C5–C6, T11–L1, and T4–T6. The type and site of spine injuries depend on the mechanism of injury and the age of the victims. Motorcycle injuries usually cause thoracic spine trauma. High-level falls are associated with spinal trauma in about 25% of cases and usually involve the lower thoracic and lumbar spine.

Cervical spine injuries pose a special challenge because of the potential catastrophic consequences of any associated cord injury. The overall incidence of cervical spine injuries in blunt trauma is about 3% and increases with age. In the presence of severe head trauma, the incidence of cervical spine trauma increases to about 10%. Very young or very old patients are more likely to suffer injuries of the upper cervical spine than younger adults who are more likely to have lower cervical injuries. In about 85% of blunt cervical spine injuries, there is a fracture; in about 10%, there is subluxation without fractures; and in about 4%, there is isolated cord injury without fracture or dislocation. Very young or very old patients are more likely to suffer cord injuries without skeletal trauma than young adults.

Anatomy

Good knowledge of the key parts of the cervical, thoracic, and lumbar spine vertebra is essential in understanding the various types of spinal injuries (Figure 7.1 A,B, Figure 7.2 A,B).

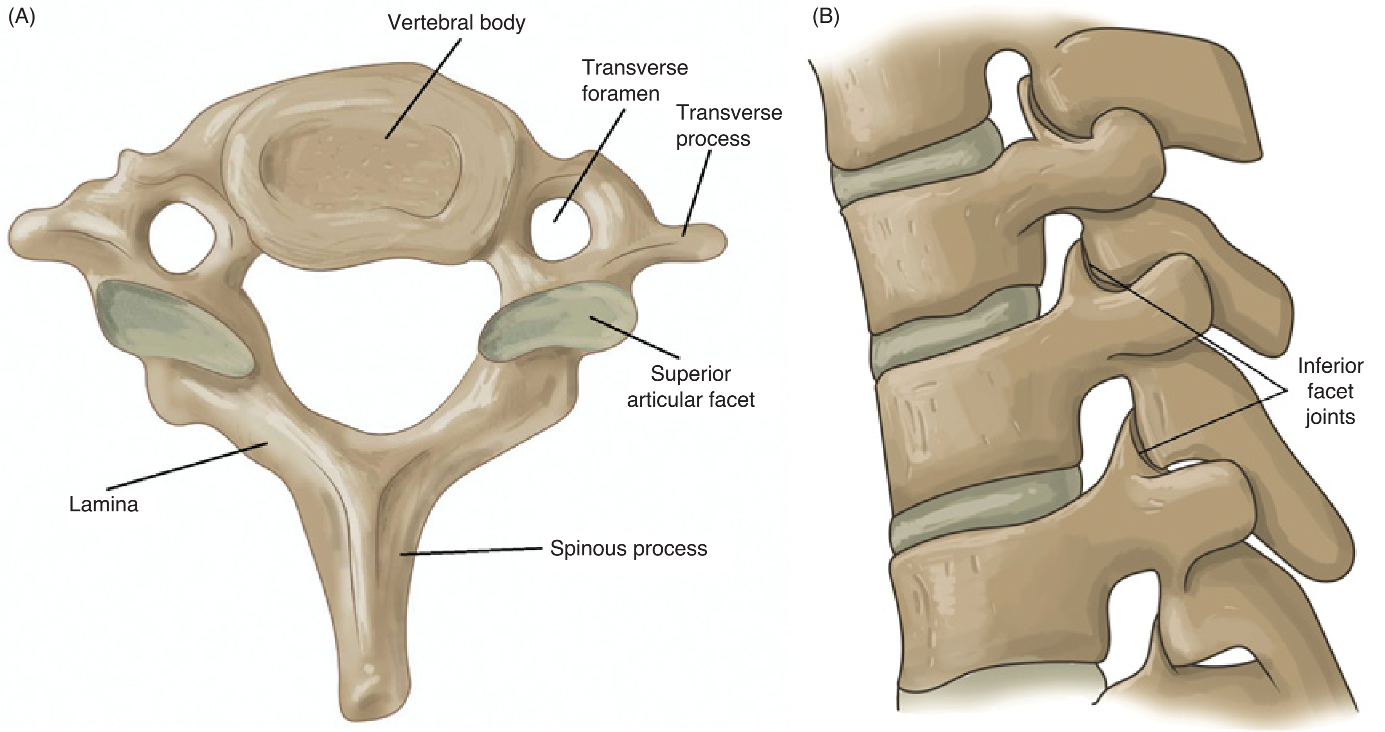


Figure 7.1 A,B Superior view of the seventh cervical vertebra (A). Detail of the facet joints of the cervical vertebra (B).

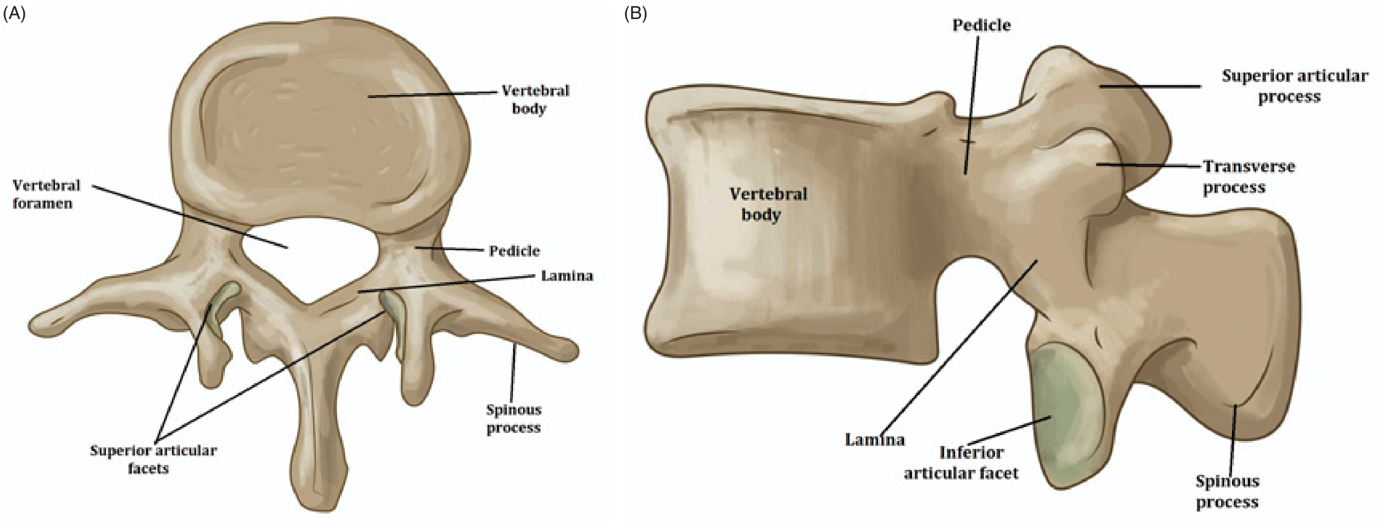


Figure 7.2 A,B Superior view of the lumbar vertebra (A). Lateral view of the lumbar vertebra (B).

Clinical Examination

All trauma victims must be thoroughly evaluated for the possibility of a spinal injury. Blunt trauma patients should have the spine immobilized at first medical contact and remain in spinal immobilization until the integrity of the cord and spinal column can be verified. In patients with multiple severe injuries, the spinal clearance can be deferred until more critical injuries have been addressed, provided that immobilization of the spine and adequate precautions are maintained.

Patients with spinal fractures experience pain, and examination will reveal spinal tenderness on palpation and sometimes local swelling on inspection. Patients may also demonstrate a spinal deformity or step-off. However, patients who are unable to report pain because of concomitant head injury or intoxication may have occult spinal injuries and should remain immobilized until they can be accurately evaluated.

Patients with spinal cord injury manifest symptoms according to the spinal cord level affected. With complete cord transection, all motor and sensory function below the level of the lesion is lost. Priapism is common in males after complete cord transection, and it usually resolves within a few hours. The highest intact sensory level should be marked on the patient to determine whether the cord lesion is progressing proximally on subsequent examinations. A careful motor examination should corroborate the level of the cord lesion. Assessment of rectal tone and perianal sensation is important in detecting any sparing of lower cord segments, which significantly improves the prognosis.

The syndrome of spinal cord injury without radiographic abnormality (SCIWORA) can occur in any age group but is particularly more common in children or in old age. Neurologic deficits may be delayed for many hours, and by definition, radiographs are normal. Consequently, it may be difficult to make this diagnosis on initial evaluation. Patients who report persistent paresthesia should undergo CT scan or MRI investigations.

Spinal shock is common in the immediate period after injury and consists of flaccid paralysis and loss of sensation and all spinal reflexes below the level of the lesion. During this phase the bulbocavernosus reflex (anal sphincter contraction with stimulation of the glans or urethra) is absent. In many cases, no definitive prognostication regarding the severity or level of the spinal cord lesion can be made while spinal shock is present. The spinal shock might last from a few hours to a few days. The first reflexes to return are the anal and bulbocavernosus reflexes, and their return signifies the end of the spinal shock.

Neurogenic shock is the hemodynamic effect of sympathetic denervation that results in vasodilation and hypotension. It occurs after transection of the cervical or the upper thoracic spinal cord. In high cervical cord injury, the hypotension is associated with severe bradycardia, because of disruption of the sympathetic innervation to the heart. In lower cervical or upper thoracic spinal cord transection, the hypotension is associated with tachycardia. Regardless of the presence of neurogenic shock, hypotension must be assumed to be due to hemorrhage and a diligent search for sources of blood loss must be made.

Investigations

Trauma patients requiring cervical spine clearance can be classified into one of three categories: asymptomatic, symptomatic, or nonevaluable (obtunded/comatose).

Patients who are fully alert, not intoxicated, have no significant distracting injuries, and who are asymptomatic (no neurological symptoms, no neck pain on palpation, active and passive flexion/extension) can be cleared safely based on clinical examination alone without imaging studies.

Trauma patients who present with neck pain, spinal deformity, and/or neurologic symptoms require radiographic imaging. The standard radiological evaluation in a multiple trauma patient used to include a cervical spine X-ray series (anteroposterior, lateral, open mouth view). This approach has largely been replaced by routine CT scan evaluation. A cervical CT scan with coronal and axial reconstructions has a sensitivity of 99% of detecting a cervical spine fracture or instability. This modality can also be rapidly accomplished as an extension of a primary CT of other body regions (head, thorax, abdomen, pelvis, etc.). Patients presenting with neurologic deficits and/or suspected ligamentous injuries should also be evaluated with a cervical MRI scan. The MRI can also provide accurate visualization of any cord lesion. Plain X-rays with cervical flexion–extension are rarely used and are potentially dangerous. If flexion–extension radiological evaluation is requested, it should be performed only in awake and alert patients, under the supervision of a physician.

The clearance of the cervical spine in obtunded and comatose trauma patients remains controversial. These patients should be evaluated with CT scan of the cervical spine. There is a less than 1% risk of a trauma patient having a purely ligamentous cervical spine injury that is not identified on CT scan. Some centers practice cervical spine clearance on the basis of normal CT scan, as read by a neuroradiologist. Others are more cautious and perform cervical spine MRI on all unevaluable patients with a normal CT scan. This is a controversial approach, and may be impractical and potentially risky to transfer a severe multi-trauma patient for MRI scan. Many serious complications occur during transportation of the critically injured patients. In addition, although cervical MRI is very sensitive at detecting ligamentous injury, it may over-read and lead to a high rate of false-positive findings that could potentially lead to unnecessary interventions. The use of dynamic flexion–extension radiographs or upright cervical radiographs in ruling out ligamentous injuries in obtunded trauma patients has not been clinically validated and may be harmful (Table 7.1, Table 7.2, Table 7.3, Table 7.4).

Table 7.1 Clinical evaluation of the cervical spine.

Asymptomatic
Awake/alert
No neck pain/tenderness
Normal neurologic exam
No intoxication or distracting injury
Symptomatic
Neck pain/tenderness
Abnormal neurologic exam
Distracting injury
Major/low-energy trauma
Unevaluable
Obtunded/comatose
Intoxication
Abnormal cognitive function that interferes with clinical examination

Table 7.2 Algorithm for the evaluation of the cervical spine.

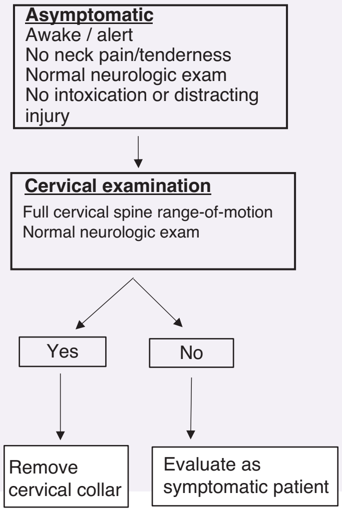


Table 7.3 Algorithm for the evaluation of the cervical spine in symptomatic patients.

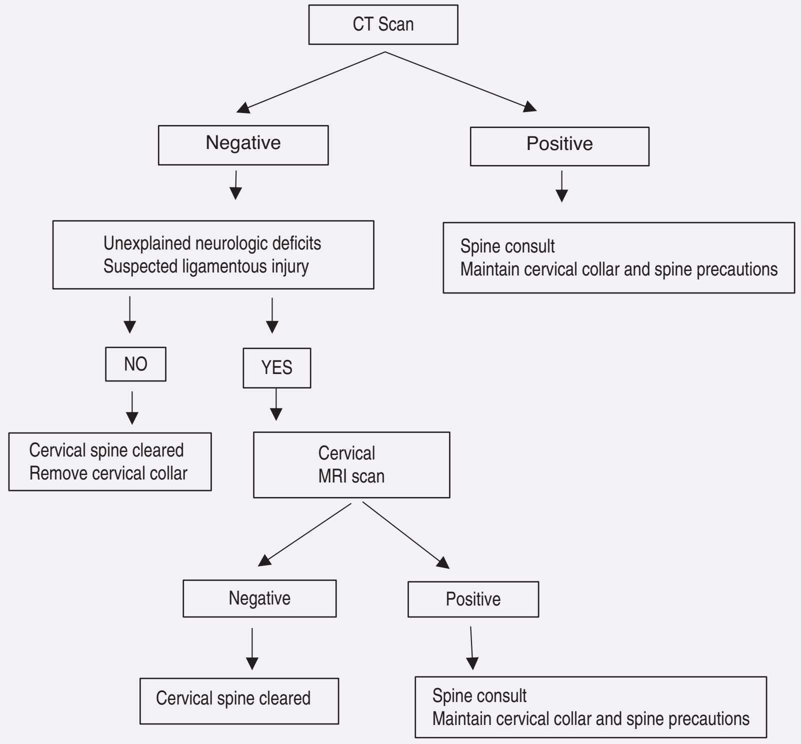
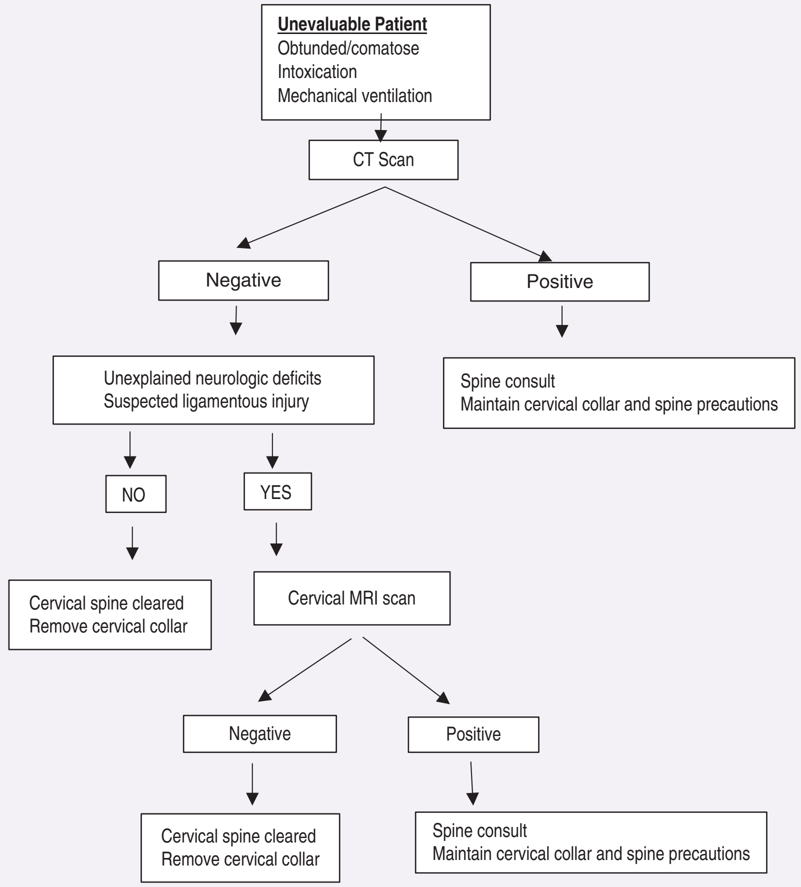

CT Scan
Negative
Positive
Unexplained neurologic deficits
Suspected ligamentous injury
Spine consult
Maintain cervical collar and spine precautions
NO
YES
Cervical spine cleared
Remove cervical collar
Cervical
MRI scan
Negative
Positive
Cervical spine cleared
Spine consult
Maintain cervical collar and spine precautions

Table 7.4 Algorithm for the evaluation of the cervical spine in clinically unevaluable patients.


Unevaluable Patient
Obtunded/comatose
Intoxication
Mechanical ventilation
CT Scan
Negative
Positive
Unexplained neurologic deficits
Suspected ligamentous injury
Spine consult
Maintain cervical collar and spine precautions
NO
YES
Cervical spine cleared
Remove cervical collar
Cervical MRI scan
Negative
Positive
Cervical spine cleared
Remove cervical collar
Spine consult
Maintain cervical collar and spine precautions

General Management

As with severe head injury, prevention of secondary cord injury is the highest priority. Although cord lesions may progress in spite of proper medical care, avoidance of hypotension, hypoxia, seizure, hypoglycemia, hyponatremia, and mishandling of the patient are essential to avoid unnecessary deterioration.

Airway assessment occurs simultaneously with spinal immobilization. Patients with complete spinal cord injury above the level of C-4 will be apneic, because of paralysis of the diaphragm and all other respiratory muscles. Immediate endotracheal intubation and mechanical ventilation should be performed. The endotracheal intubation should be done by the most experienced physician, with in-line stabilization of the spine by an assistant. Alternatively, fiberoptic intubation may be considered in selected cases, when the patient can cooperate and is not hypoxic.

Treat aggressively any hypotension with intravenous fluids or blood products as needed and in the appropriate cases with vasopressors. Maintain a good mean arterial pressure to prevent secondary cord damage.

Neurogenic shock usually responds to fluid administration, but pressor agents may be required to avoid hypotension and resultant hypoperfusion of the injured spinal cord. Severe bradycardia in high cervical cord injuries responds well to atropine administration. Patients with high spinal cord injury lose heat easily because of the peripheral vasodilation, and warming devices should be used to avoid hypothermia.

The therapeutic role of routine steroid administration in blunt spinal cord trauma is currently a controversial issue, and professional society guidelines do not support their use.

A Foley catheter should be placed as soon as the primary survey is completed. Nasogastric decompression is indicated if ileus develops.

Emergency surgical decompression of the cord and spinal fixation should be performed in patients with incomplete cord injuries, especially in cases with deteriorating neurological examination, and in the presence of significant epidural or subdural hematomas. The role of emergency spinal operation in complete cord transections is questionable, and most neurosurgeons or spinal surgeons do not support it. However, an elective spinal fixation should be considered as early as possible in unstable fractures or dislocations in order to facilitate rehabilitation.

Tips and Pitfalls

- Elderly patients who present with low-speed vehicular accidents or ground-level falls can suffer fractures because of their brittle or osteoporotic spines. A low threshold for obtaining CT scan should be maintained in trauma involving high-risk patients.
- Patients with high cervical cord injury (above C-5) and quadriplegia should have endotracheal intubation and mechanical ventilation soon after admission. These patients often decompensate and develop severe respiratory failure a few hours after admission, requiring emergency intubation under suboptimal conditions, resulting in preventable morbidity or mortality.
- The diagnosis of central cord syndrome is often initially misdiagnosed. because the full clinical picture might develop over many hours. The inexperienced physician might misdiagnose the weakness of the upper extremities with nearly normal lower extremity motor function as substance intoxication or malingering.
- Some patients who develop neurologic deficits do so after contact with medical personnel. Although some of these deficits would occur due to progressive edema or ischemia, others may be the result of inadequate care and poor spinal immobilization during transfer of the patient from stretcher to X-ray table or CT scan.
- Intoxicated or head-injured patients should have spinal precautions maintained until they can reliably be evaluated by CT scan or clinical examination.
- There is often confusion between spinal shock (loss of reflexes and motor/sensory function) and neurogenic shock (hemodynamic effects of sympathectomy due to high spinal cord lesions manifesting as hypotension with or without bradycardia, depending on the level of the cord injury). These terms are not interchangeable and should be used correctly to avoid miscommunication.
- The inexperienced physician may incorrectly record normal or reduced rectal tone in the presence of a complete cord transection. This documentation may result in medicolegal complications because it can be claimed that a partial cord injury was allowed to progress to complete injury. If not sure, the physician should record "rectal tone difficult to evaluate."
- The inexperienced health care provider may mistake reflexive minor extremity movements in complete cord injury as active movements. Such documentation may give the impression of partial cord injury and raises the expectations of the family. Only voluntary movements count!
- Chance fracture of the lumbar spine is frequently associated with a small intestinal injury that may be initially occult.
- Patients who present with calcaneal fracture(s) after jumping from a height should be screened for coexistent lumbar compression fractures because these fractures are commonly associated.
- Approximately 10% of spinal fractures are associated with another noncontiguous spine fracture; thus the finding of any spinal fracture should initiate a search for other fractures elsewhere in the spine.

Spinal Cord Injuries

Complete Spinal Cord Transection

Complete transection of the spinal cord is a devastating injury. Transection above the level of C 4–5 results in acute respiratory failure as the nerve supply to both the diaphragm (C 3–5) and intercostal muscles is lost. Such patients frequently die at the scene of the injury, unless immediate ventilation is provided.

At more distal levels, acute spinal cord transection results in complete flaccid motor paralysis and loss of sensation and deep tendon reflexes below the level of the injury. There is urinary retention and diminished or absent rectal sphincter tone. In males, transient priapism is very common and indicates complete cord transection, although it often resolves by the time the patient arrives in the emergency department (Figure 7.3 A,B, Figure 7.4, Figure 7.5, Figure 7.6).

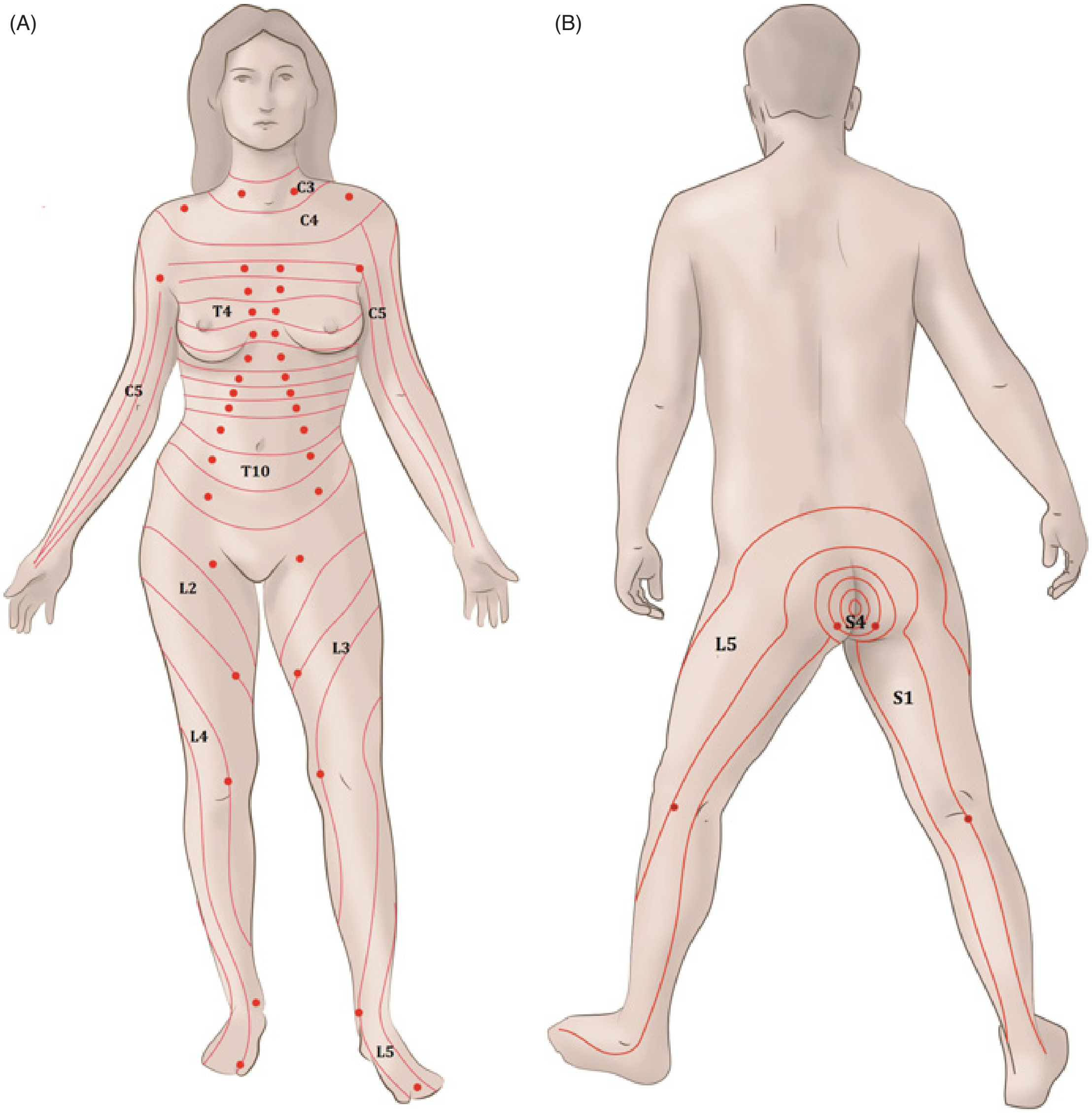


Figure 7.3 A,B Illustration showing anterior dermatomes (A). Illustration showing posterior dermatomes (B).

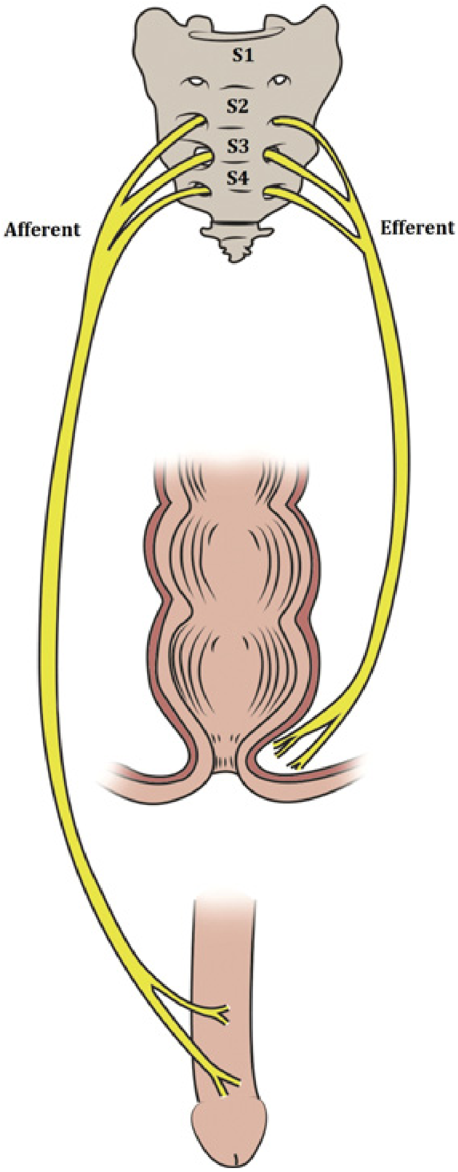


Figure 7.4 Illustration of the bulbocavernosus reflex arc. Stimulation of the glans or the urethra causes contraction of the anal sphincter.

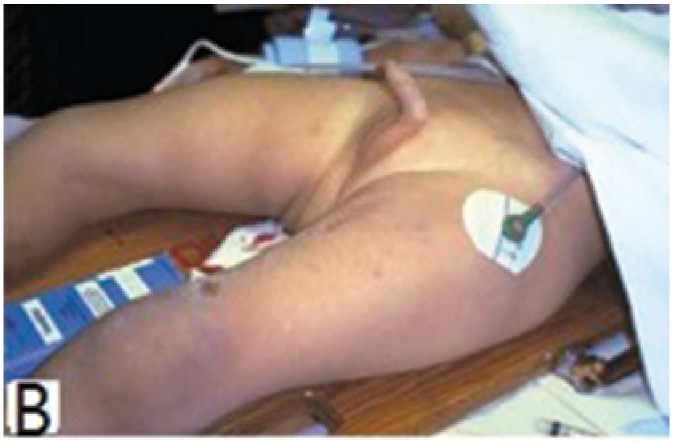


Figure 7.5 Priapism in a child with complete transaction of the spinal cord. The presence of priapism is a bad prognostic sign.

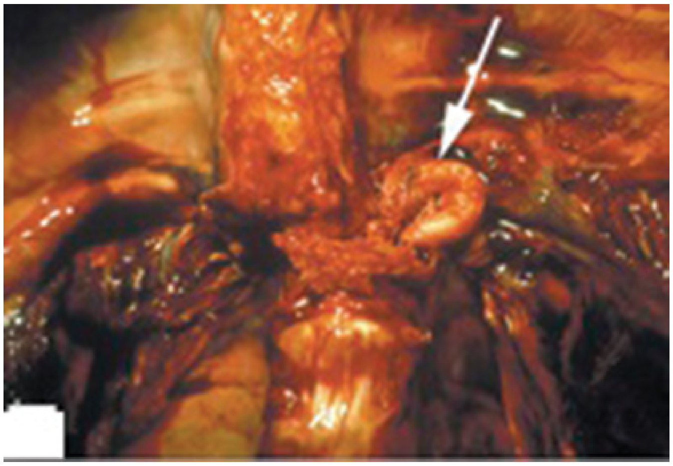


Figure 7.6 Autopsy photograph of severe distraction of the spinal column and extrusion of the spinal cord.

Loss of sympathetic innervation below the level of the cord injury results in loss of vasomotor tone and hypotension. In cervical cord injuries, loss of sympathetic innervation to the heart prevents the normal response of reflex tachycardia. Consequently, the hemodynamic picture of hypotension combined with bradycardia, and warm, flushed skin, constitutes the classic syndrome of neurogenic shock secondary to high cord transection. Transection of the upper thoracic cord usually results in hypotension associated with tachycardia. Inability to vasoconstrict also prevents the normal response to cold stress, and these patients are at risk for hypothermia. Treatment is initially directed at restoring intravascular volume and ensuring that hypotension is not due to occult blood loss. If volume infusion does not restore adequate blood pressure, pressor agents such as dopamine are indicated to improve perfusion and consequently the survival of the spinal cord proximal to the transection.

During the acute phase of spinal cord injury, all distal reflexes are absent and the patient is said to be in "spinal shock" (not to be confused with neurogenic shock with its hemodynamic manifestations). To confirm that all reflexes are absent, the most distal reflex arc or bulbocavernosus reflex is examined. Stimulation of the glans or clitoris or tugging on a Foley catheter normally produces a reflex anal sphincter contraction. During spinal shock, no response will occur. During this phase, it is possible that spinal cord dysfunction is due to concussion or contusion of the cord, and significant recovery of function can occur. Over the ensuing 24–48 hours, spastic reflexes that are typical of an established spinal cord injury begin to appear. One of the first such reflex to return is the bulbocavernosus reflex. Once this reflex reappears, the period of spinal shock has ended and significant recovery is unlikely. Sparing of sensation in the perianal area should be elicited, as this represents a positive prognostic sign of potential recovery of spinal function.

Anterior Cord Syndrome

Anterior cord syndrome results from direct injury to the anterior part of the spinal cord by a fracture or penetrating trauma or to the anterior spinal artery, producing infarction of the anterior spinal tracts. It may also result from prolonged cross clamping of the aorta or prolonged hypotension. Clinically, there is bilateral loss of motor function, light touch, pain, and temperature sensation below the level of the injury. Posterior column function (position and vibration sense) is preserved (Figure 7.9).

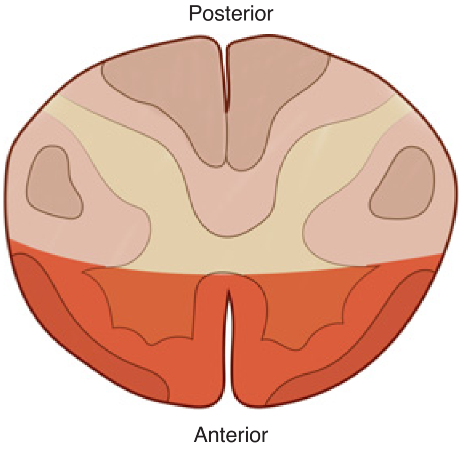


Figure 7.9 Schematic drawing of spinal cord tracts affected in anterior cord syndrome.

Upper Cervical Spine Dislocations

There are multiple strong ligamentous attachments from the cervical spine to the base of the skull. These include the anterior and posterior longitudinal ligaments, the anterior and posterior atlanto-occipital membranes, the apical ligament from the odontoid, and the capsular ligaments of the atlanto-occipital joint.

Separation of the cervical spine from the base of the skull is almost invariably fatal at the scene of the trauma. Fatalities occur from disruption of the spinal cord above the level of C-4, which results in complete paralysis of respiratory effort and asphyxial death or from injury to the brain stem or vertebral arteries. In patients who survive to reach a hospital, mortality is high due to brain stem injury, associated head and systemic trauma, and prolonged coma with its attendant complications. Nevertheless, survivors have been reported, and a full resuscitative effort should be made.

Atlanto-Occipital Dislocation

Atlanto-occipital dislocation occurs from the application of massive shearing force to the head in an anteroposterior direction as seen in high-speed motor vehicle crashes. The injury is primarily ligamentous, although associated fractures of the face and skull are common (Figure 7.10 A–C).

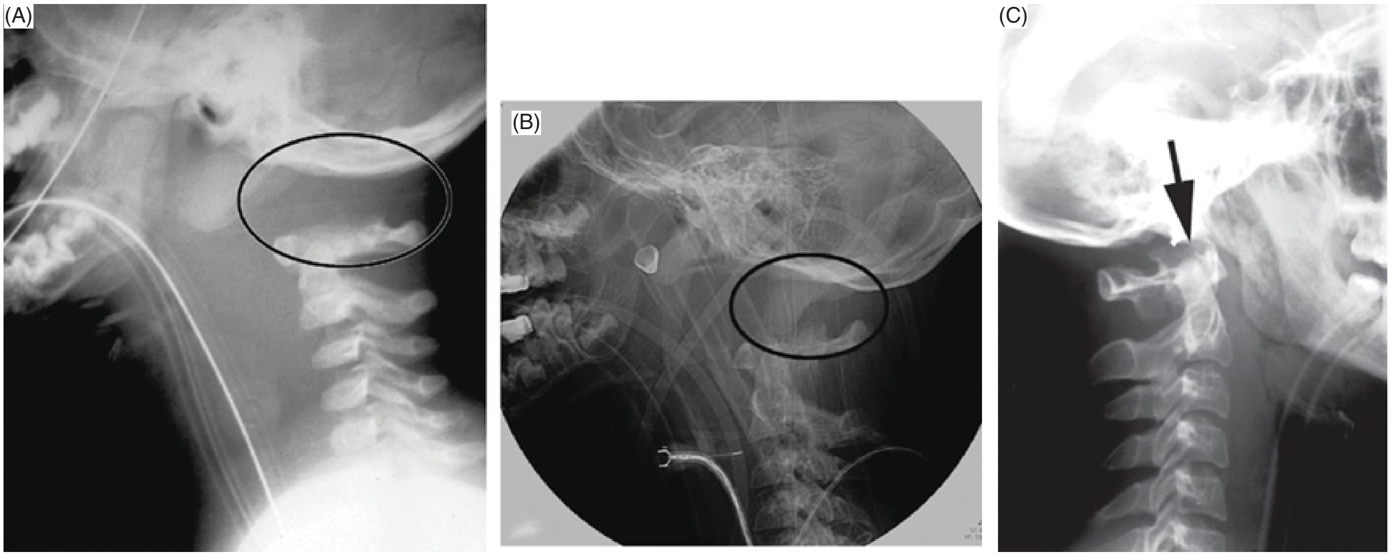


Figure 7.10 A–C Lateral radiographs of the cervical spine in young children showing severe atlanto-occipital dislocation and massive soft tissue swelling anterior to the spinal column (A,B). Lateral radiograph of the cervical spine in an adult showing a subtle atlanto-occipital dislocation (arrow) with significant soft tissue swelling anterior to the spinal column (C).

Atlantoaxial Dislocation

Atlantoaxial dislocation is a rare injury of unclear mechanism. There is disruption of the ligaments that connect the odontoid process to the ring of C-1, which displaces superiorly. Neurologic deficits are uncommon with superior dislocation (as shown) or when associated with fracture of the odontoid, although the condition is unstable due to disruption of the ligaments. Anterior dislocation is usually fatal as the spinal cord is compressed against the intact odontoid (Figure 7.11).

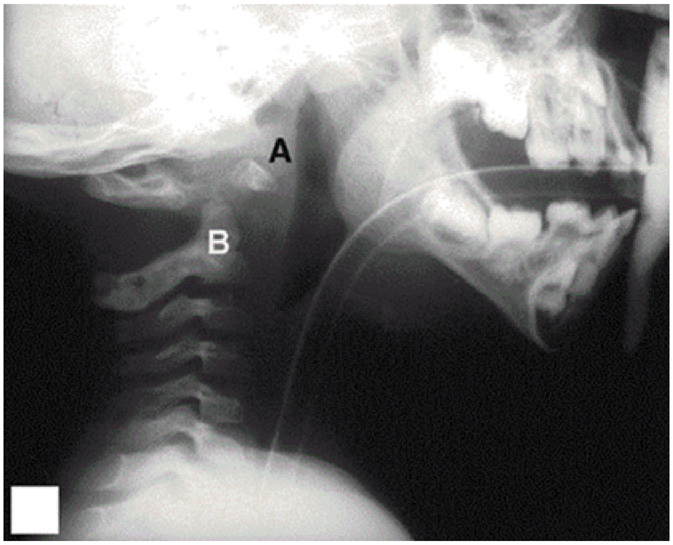


Figure 7.11 Lateral radiograph of the cervical spine in a child showing atlantoaxial dislocation. The ring of C-1 (A) is seen lying completely above the tip of the odontoid process (B).

Rotatory Subluxation of C-1 on C-2

Another form of ligamentous injury in this area is rotatory subluxation of C-1 on C-2, which results from torsional forces applied to the head and neck. Neurologic deficits are rare because the space for the spinal cord is not encroached upon (Figure 7.12, Figure 7.13, Figure 7.14).

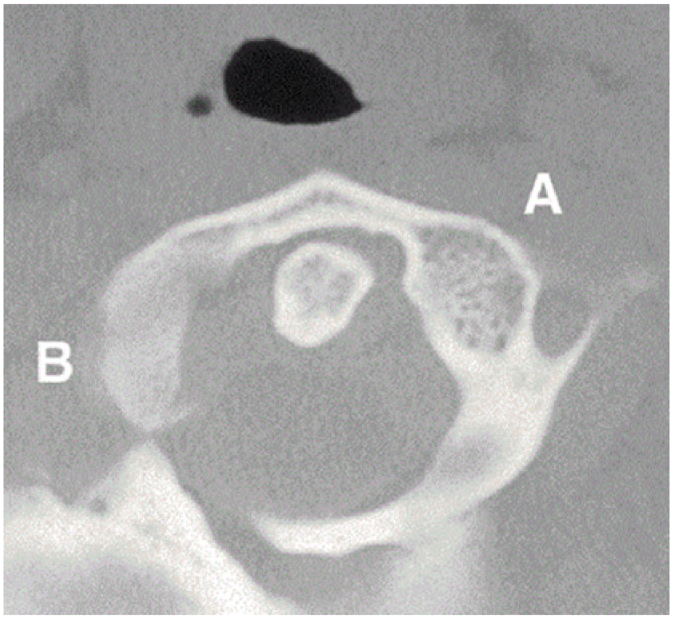


Figure 7.12 CT scan of C-1 and C-2 showing the left lateral mass of C-1 (A) rotated anteriorly and the right lateral mass rotated posteriorly (B).

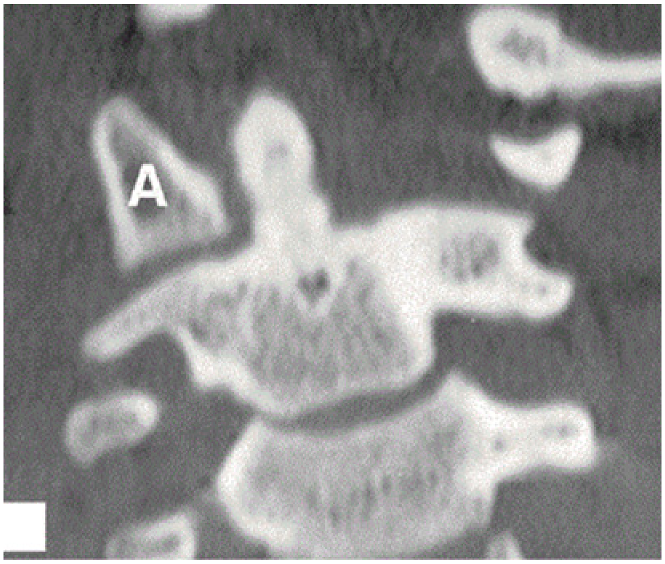


Figure 7.13 CT scan of C-1 and C-2 in the anteroposterior orientation. The right lateral mass (A) is seen clearly, but the left lateral mass of C-1 has rotated posteriorly out of view.

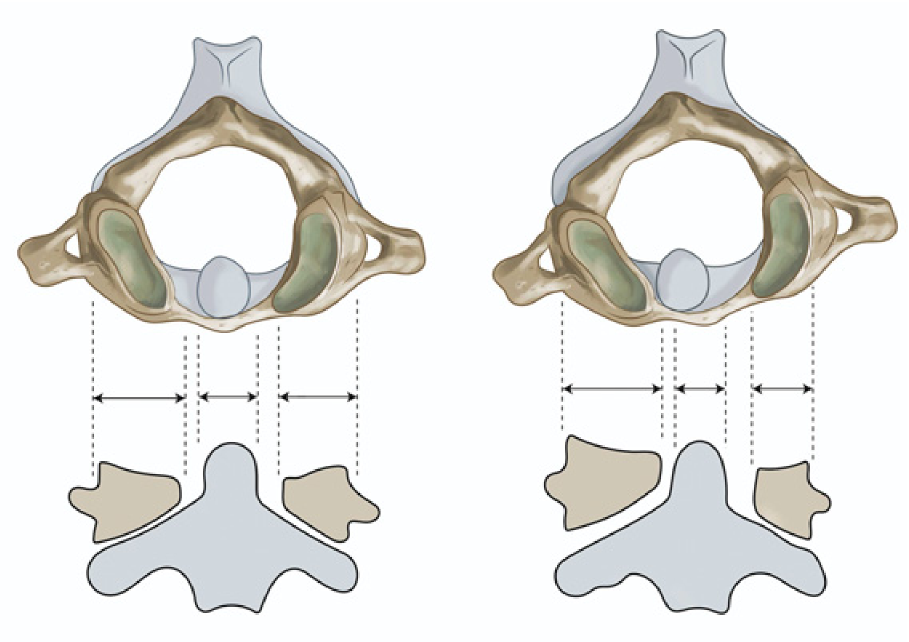


Figure 7.14 Schematic drawing of rotator subluxation of C-1 on C-2.

The plain X-ray appearance of this injury is subtle and may be confused with a burst fracture of C-1. In the case of rotatory subluxation, one lateral mass rotates anteriorly and the other posteriorly. The anteriorly subluxed lateral mass appears larger and closer to the odontoid process, whereas the other lateral mass appears smaller and farther from the odontoid. On the plain radiographic open-mouth odontoid view, the distance from the odontoid to the lateral mass is increased on one side and decreased on the other, in contrast to a burst fracture of C-1, in which both lateral masses are displaced laterally. In burst fractures that occur on only one side of the ring of C-1, that lateral mass will be displaced laterally, whereas the unaffected side will show a normal relationship of the lateral mass of C-1 to the articular plate of C-2.

Ligamentous Injuries

Flexion and extension views of the cervical spine used to be supplementary radiographs in patients with increased soft tissue swelling anterior to the vertebral bodies or suspicion of misalignment on the lateral cervical spine film.

The patient must be awake and able to cooperate. He or she should be instructed to actively flex and then extend the neck up to the point of experiencing pain and no further. At the point of maximal voluntary flexion and extension, a lateral radiograph is obtained. The patient's neck should never be passively flexed or extended by the physician during this examination. Positive findings are increased subluxation of the vertebrae in either flexion (posterior ligaments disrupted) or extension (anterior ligaments disrupted). This investigation has been replaced by MRI, and very few centers still perform flexion/extension studies. CT scan is relatively insensitive in detecting ligamentous injuries or misalignment of the spine (Figure 7.15, Figure 7.16, Figure 7.17).

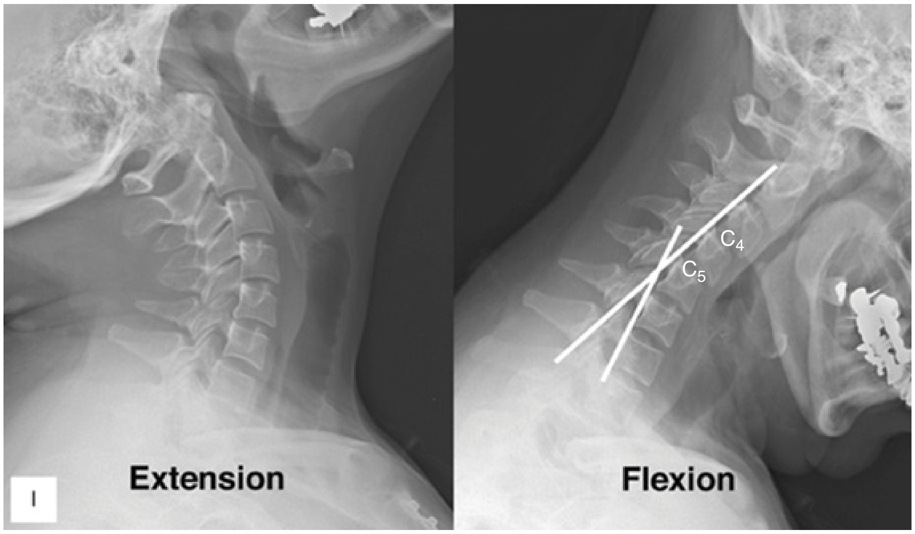


Figure 7.15 Flexion–extension lateral radiographic series. The extension view appears normal, but the flexion view shows significant angulation and anterior subluxation of C-4 on C-5, indicating posterior ligamentous disruption.

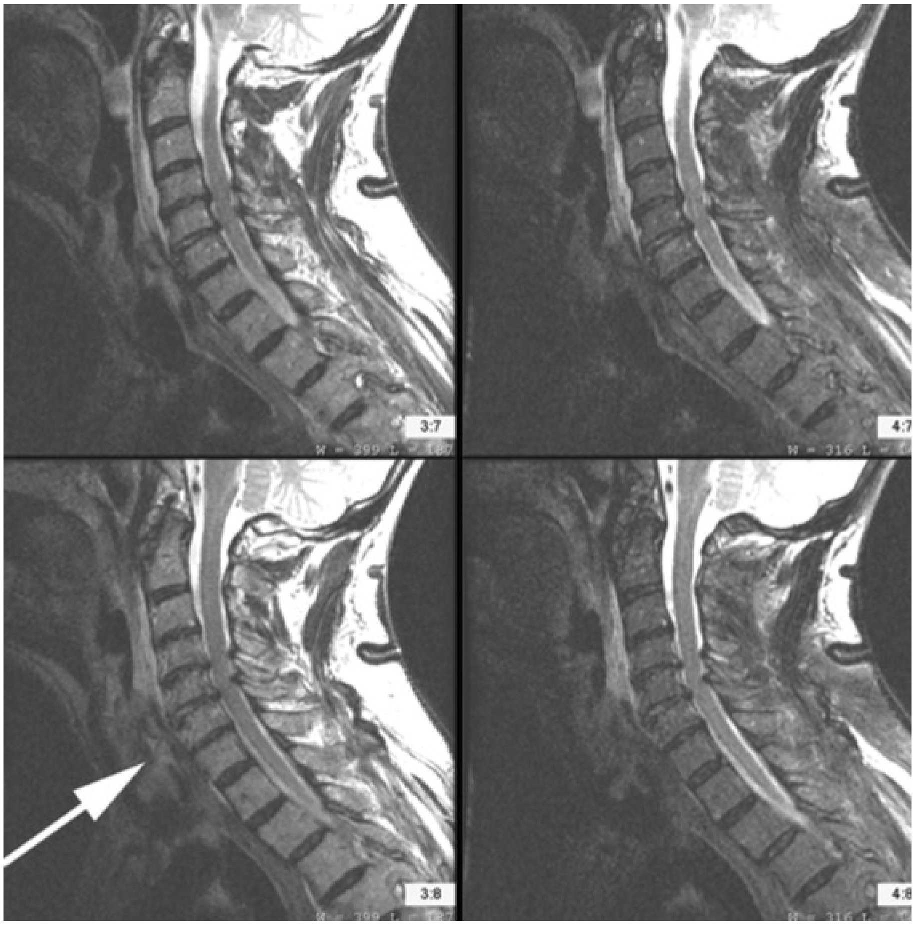


Figure 7.16 T2-weighted MRI showing ligamentous injury and soft tissue edema to the vertebral bodies of C-5 through C-7.

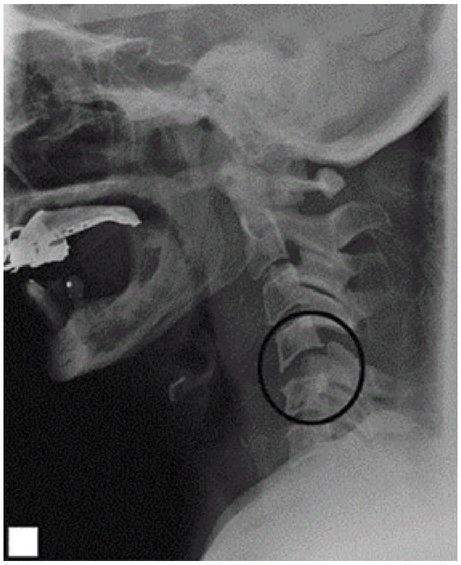


Figure 7.17 Lateral radiograph showing C-4 on C-5 subluxation.

Cervical Spine Fractures

Atlas (C-1) Fractures

C-1 or the “atlas” is a ring-shaped vertebra that articulates with the base of the skull superiorly and with C-2 inferiorly. Fractures usually result from axial compression of the head and spinal column (e.g., from diving into a shallow pool or when a passenger’s head strikes the inside of the roof of a car in a motor vehicle accident). Because of the angles at which C-1 articulates with the occiput and C-2, the axial force is translated into a lateral force at C-1, causing the fragments to burst outward. Consequently, neurologic deficits are relatively uncommon with C-1 fracture because the space for the spinal cord within the spinal canal is actually increased. A Jefferson (burst) fracture involves disruption of both the anterior and posterior arches, which may allow displacement of the lateral masses and is an unstable fracture (Figure 7.18 A–D).

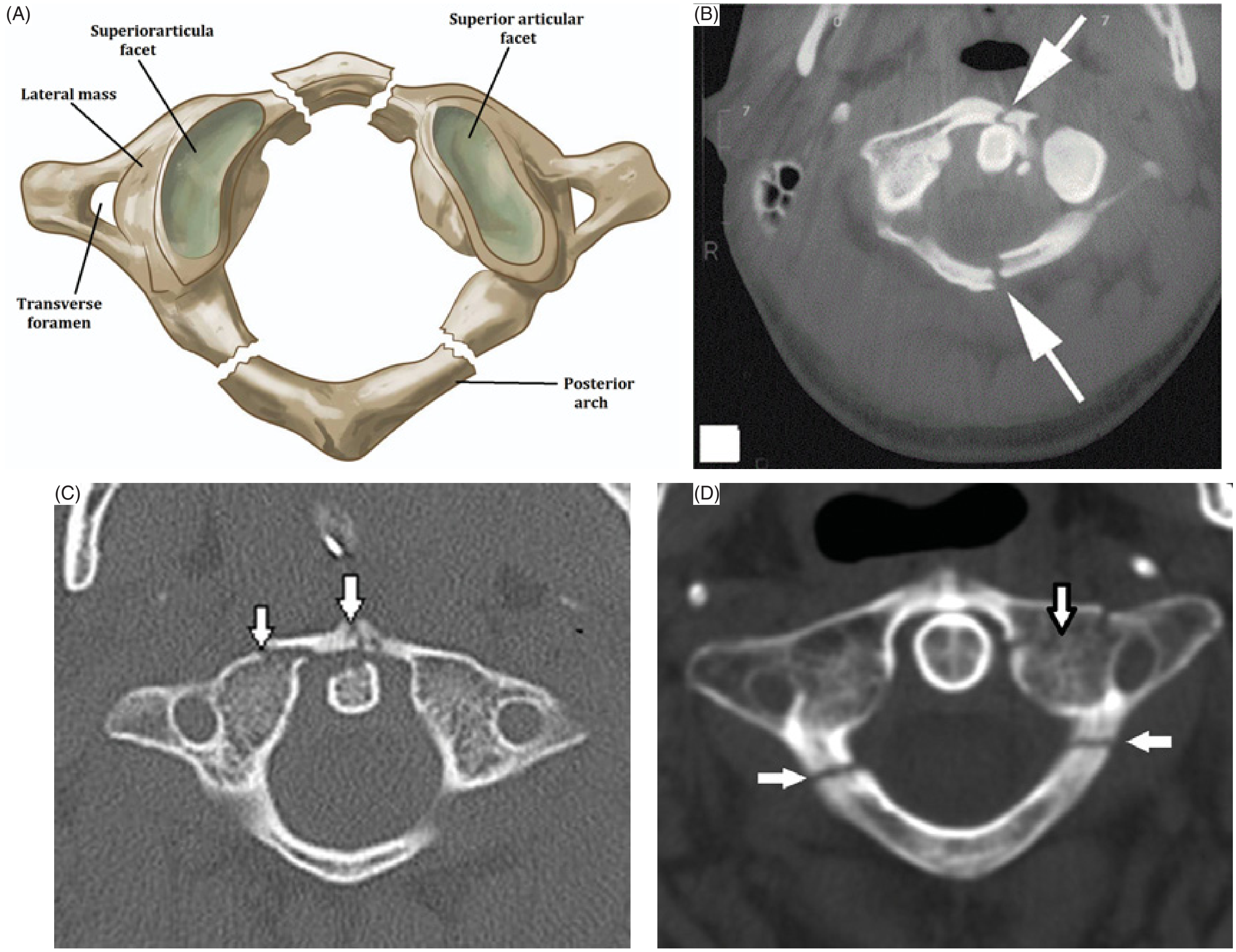


Figure 7.18 A–D Illustration (A) and CT scan (B) showing fracture of the C-1 (Jefferson fracture). Double fracture of the anterior arch of the C1 (C). CT scan showing communited fracture of the left lateral mass (black and white arrow) bilateral posterior arches (white arrows; D).

Odontoid (Dens) Fractures (C-2)

There are three types of odontoid fracture. Type I odontoid fracture occurs at the tip of the odontoid process, above the level of the alar ligaments. This is a rare fracture, caused by avulsion of the tip of the odontoid by apical ligaments attached to the base of the skull. It is a stable fracture because the alignment of C-1 on C-2 is maintained by the alar and transverse ligaments. Neurologic deficit is uncommon.

Type II odontoid fracture occurs at the “neck” of the odontoid process, below the level of the transverse ligaments. It usually results from shear forces that cause anterior-to-posterior displacement of the entire C-1–C-2 complex from the body of C-2. It is a highly unstable fracture, more frequently associated with neurologic deficits, and often complicated by nonunion.

Type III odontoid fracture runs through the vertebral body of C-2. It may be comminuted and unstable. There is usually no associated spinal cord injury unless the fracture is significantly displaced or fragments of C-2 are retropulsed into the canal.

Treatment of odontoid fractures begins with immobilization in a halo vest if there is no evidence of neurologic deficit. Operative reduction may be required for fractures with impingement on the spinal cord or for persistent instability due to nonunion of the fracture fragments (Figure 7.19 A–D).

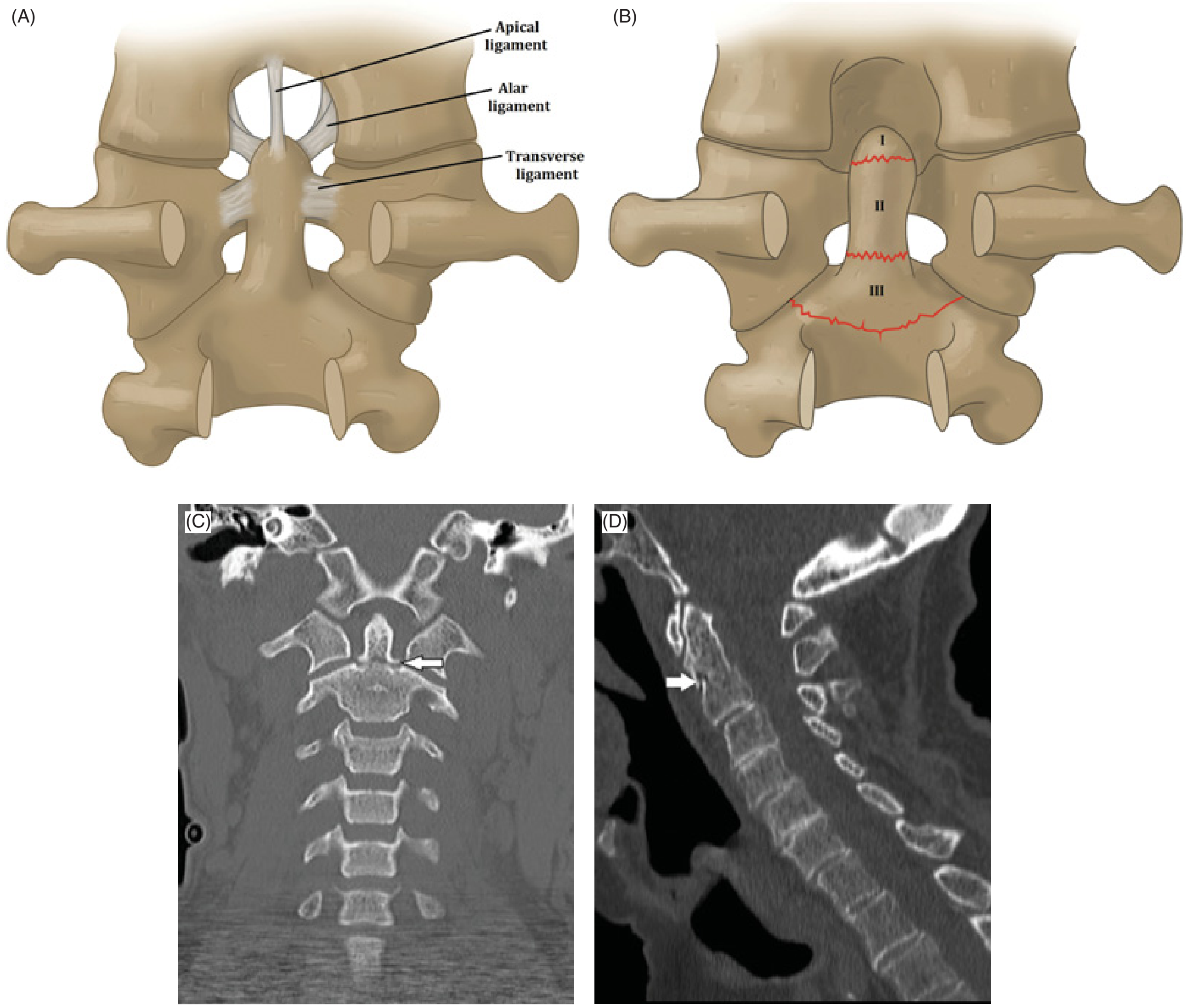


Figure 7.19 A–D Schematic showing the ligamentous attachments of C-1 and C-2 (A). Schematic showing the three types of odontoid fracture (B). Coronal and sagittal CT scans showing type III fracture of the dens (arrow; C, D).

Hangman's Fracture (C-2)

The Hangman's fracture involves both pedicles of the C-2, with spondylolisthesis of C-2 on C-3. In common usage, however, the term is applied to bilateral pedicle fractures of C-2 as well. The fracture results from hyperextension of the neck with compression of the posterior elements of C-2 by the hyperextending occiput. This is the type of injury produced by a judicial hanging – hence the name. Displaced hangman's fractures are commonly associated with severe neurologic deficits. Cord lesions at this level result in paralysis of respiratory muscles and therefore apnea, as well as complete paralysis and sensory loss distal to the lesion.

Nevertheless, patients may sustain this injury without any injury to the spinal cord. These patients should be immobilized in a halo vest and often require operative fixation (Figure 7.20, Figure 7.21 A–C).

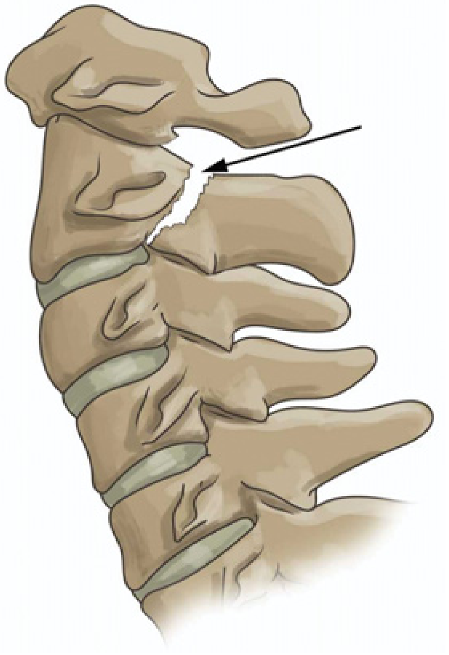


Figure 7.20 Schematic showing hangman's fracture (bilateral C-2 pedicle fracture).

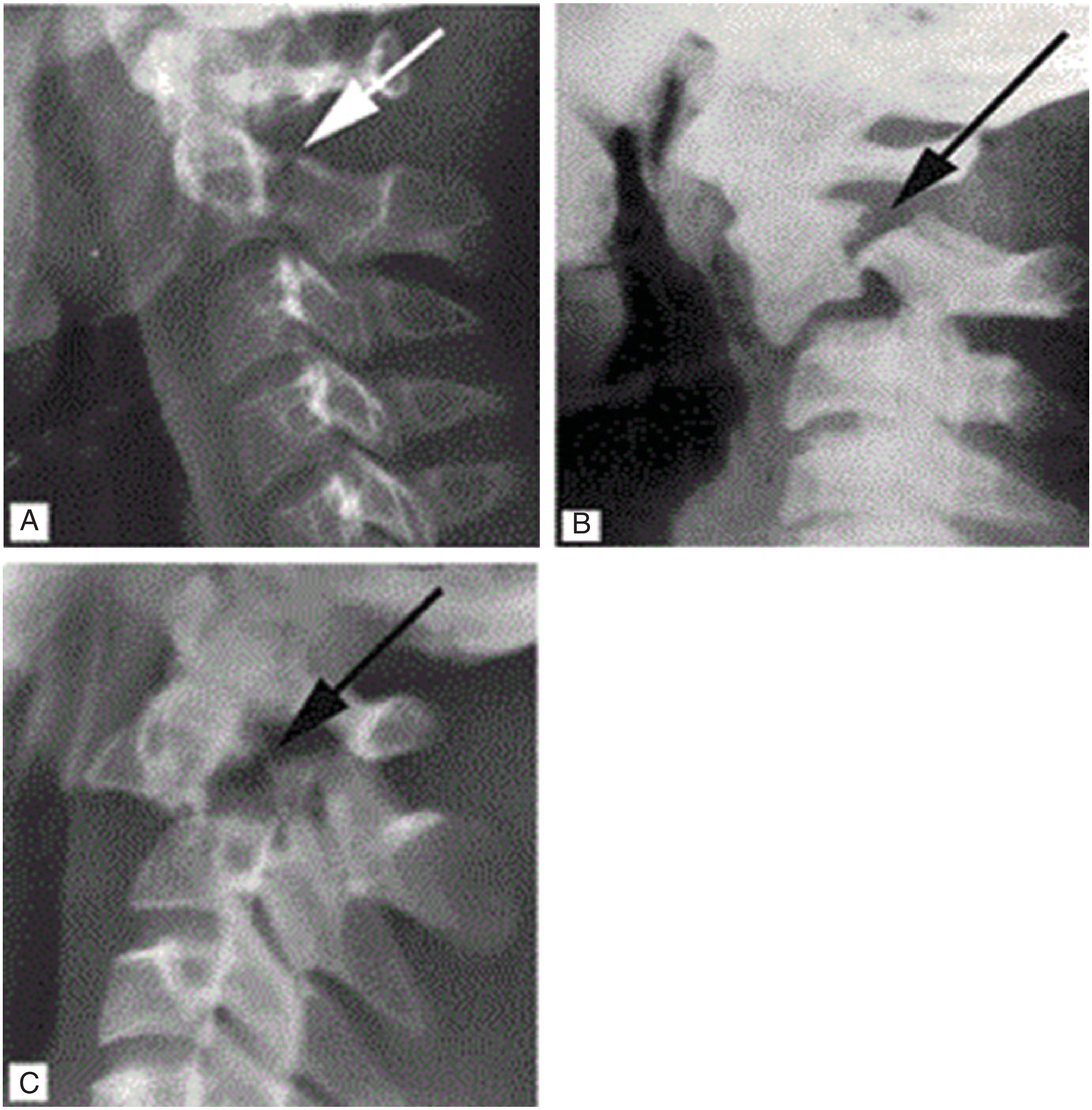


Figure 7.21 A–C Lateral cervical spine radiograph showing bilateral pedicle fracture (hangman's fracture) of C-2: undisplaced hangman's fracture (A). Moderately displaced hangman's fracture (B). Severely displaced hangman's fracture (C).

Fractures of the Lower Cervical Spine(C-3 to C-7)

Fracture Types

Vertebral body fractures are common and usually occur as a result of hyperflexion. The severity of the fracture ranges from minor to critical, depending on the degree of comminution and displacement of fragments posteriorly into the spinal canal. Unstable fractures require operative fixation and ultimately spinal fusion (Table 7.6, Figure 7.22 A–D).

Table 7.6 Classification of vertebral body fractures

Type I: Anterior inferior fragment (flexion or extension "teardrop" fracture)
Type II: Anterior wedge compression fracture
Type III: Fracture of the anterior half of the vertebral body with minimal or no displacement of the fragments posteriorly
Type IV: Comminuted "burst" fracture of the vertebral body with retropulsion of the fragments into the spinal canal

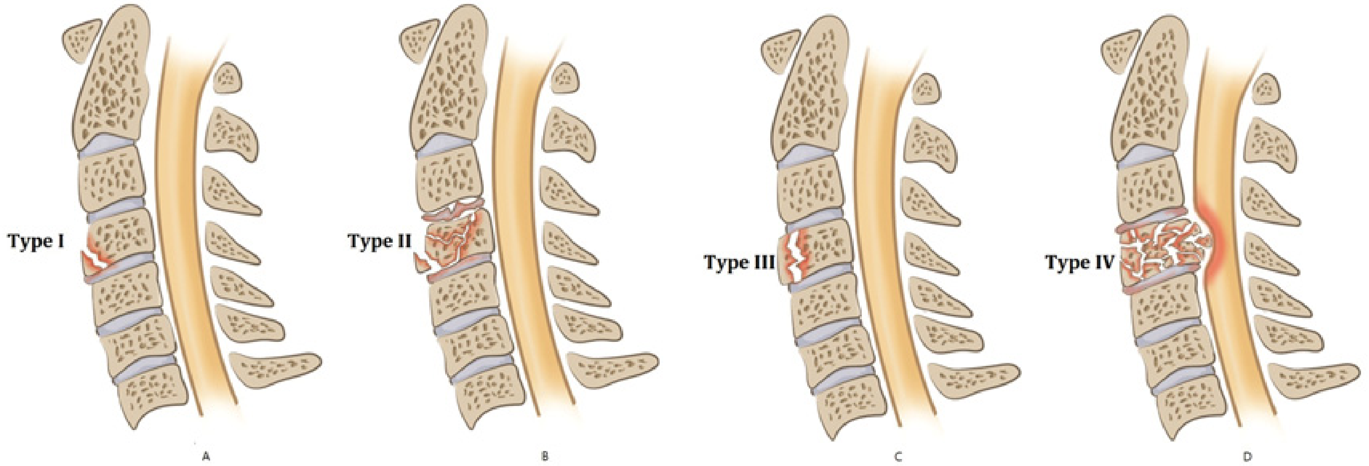


Figure 7.22 A–D Schematic of type I fracture of vertebral body (A). Type II fracture of vertebral body (B). Type III fracture of vertebral body (C). Type IV fracture of vertical body (D).

Flexion and Extension Teardrop Fracture

The flexion teardrop fracture is seen as a small triangular fragment at the anterior–inferior border of the vertebral body. The injury is caused by hyperflexion of the neck, resulting in disruption of the posterior ligaments. As the flexion continues, the anterior inferior part of a vertebral body is fractured off by contact with the subjacent vertebral body. This disrupts the anterior longitudinal spinal ligament, rendering the cervical spine unstable as both anterior and posterior ligamentous support is disrupted. This fracture occurs most commonly at the C-5 level. Although the flexion teardrop fracture appears radiographically innocuous, it is a highly unstable fracture that is associated with spinal cord injury in up to 50% of cases Often there is associated slight posterior subluxation of the affected vertebral body or of the vertebral column above it.

The extension teardrop fracture appears radiographically similar to the flexion teardrop in that a small anterior fragment is avulsed from either the inferior or superior aspect of the vertebral body. However, in an extension teardrop fracture the vertebra does not lose height. In contrast, a flexion teardrop fracture the anterior part of the body of the vertebra usually loses height from compression. The anterior longitudinal ligament is stretched during hyperextension of the neck and eventually tears, avulsing a small fragment of bone from the anterior aspect of the vertebral body. Because the posterior ligaments remain intact, the fracture is stable with the neck flexed. It may be necessary to perform flexion–extension radiographic views to demonstrate this fracture and determine its stability (Figure 7.23 A,B).

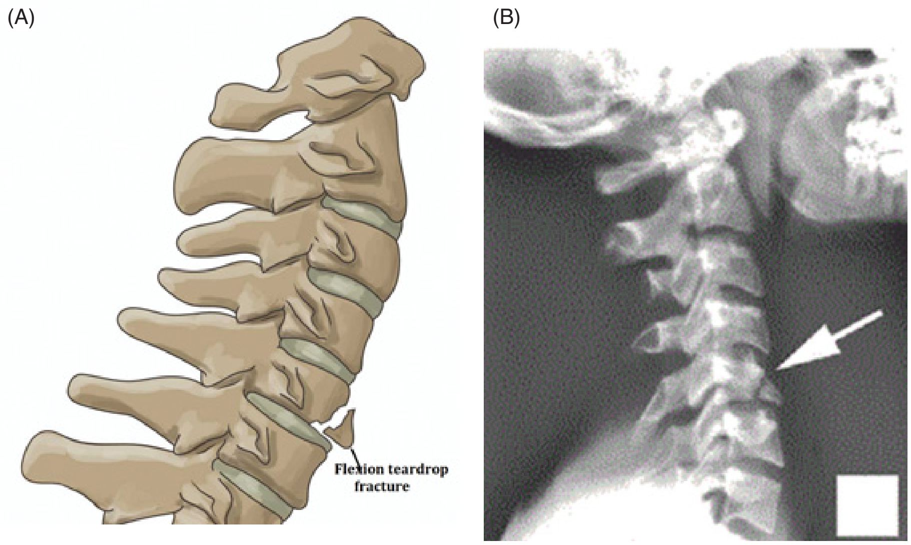


Figure 7.23 A,B Schematic of flexion and extension teardrop fractures (A). Lateral radiograph of a flexion "teardrop" fracture at the base of C-5. Arrow indicates the typical triangular anterior–inferior fragment. The flexion teardrop fracture appears as a small triangular fragment at the anterior–inferior border of the vertebral body (B). The extension teardrop fracture appears radiographically similar to the flexion teardrop, although the mechanism is opposite.

Compression Fractures of the Vertebral Body

Axial compression or hyperflexion can produce variable degrees of injury to the vertebral body, ranging from a minor anterior compression "wedge" fracture to complete bursting of thevertebral body with retropulsion of fragments into the spinal canal, causing spinal cord injury.

Anterior compression is apparent on anteroposterior radiographs of the spine as loss of height of the anterior vertebral body compared with its posterior height or compared with the adjacent vertebrae. In comparing the normally parallel vertebral endplates, severe angulation of greater than 11 degrees suggests either ligamentous disruption, facet dislocation, or anterior compression fracture. On the anteroposterior X-ray, compression fracture is seen as a loss of height of the vertebral body compared with the adjacent ones, loss of space between adjacent spinous processes, or loss of distance between the pedicles above and below the fracture. Separation of the pedicles laterally compared with those above or below suggests a burst fracture of the vertebral body (Figure 7.24 A–D).

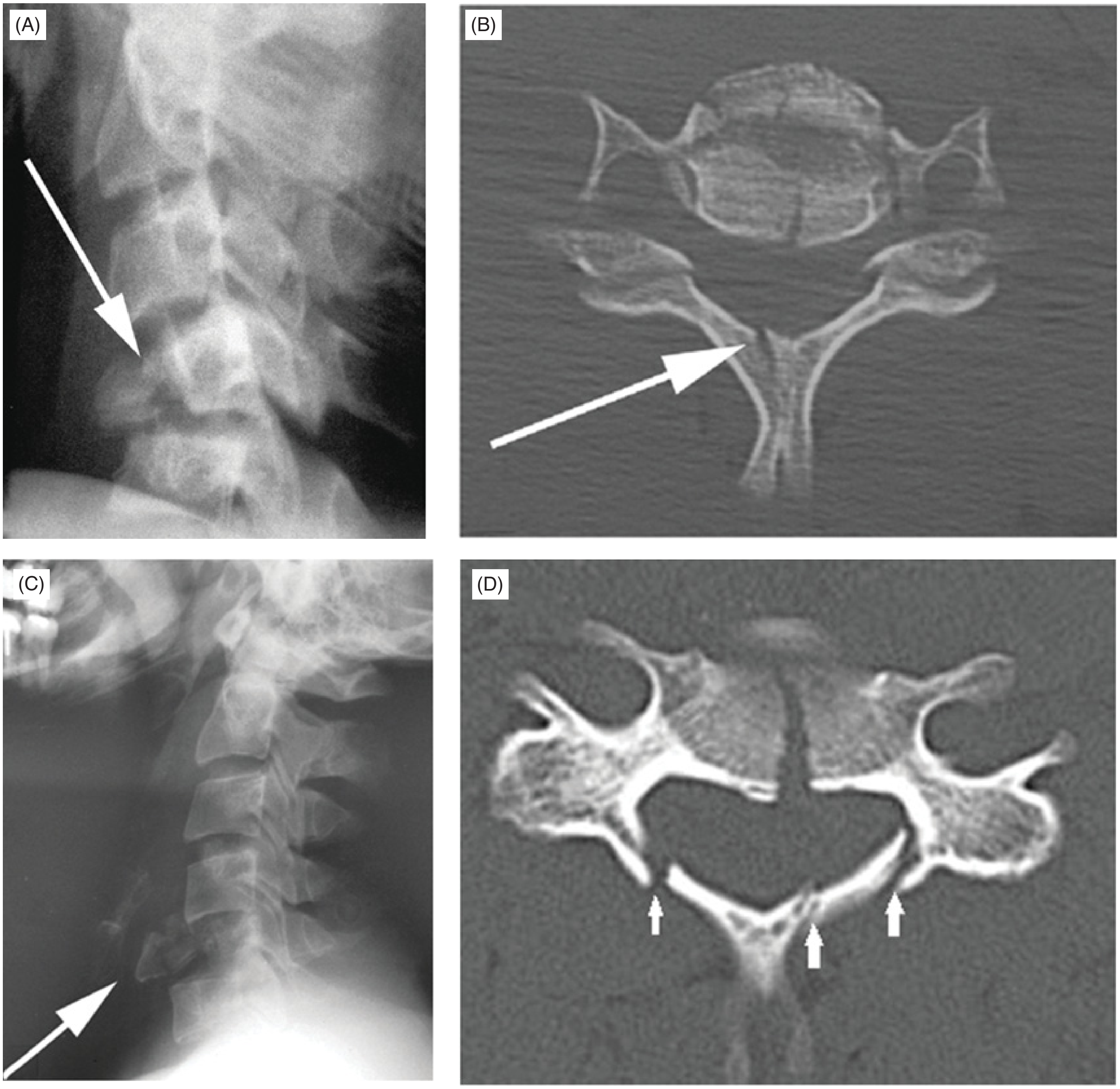


Figure 7.24 A–D Plain X-ray of a flexion-burst fracture (type IV) of C-4 with a large displaced anterior fragment (arrow), slight posterior displacement of the remainder of C-4, and severe angulation at the C-4/C-5 level (A). CT scan showing a comminuted fracture of the vertebral body with an undisplaced posterior arch fracture (arrow; B). Lateral radiograph of a comminuted type III fracture of C-5 (arrow; C). CT scan showing burst fracture of the vertebra body and fractures of the lamina (arrows; D).

Higher-grade fractures involve comminuted fragments displaced centrifugally. Consequently, plain radiographs reveal loss of vertebral height, increased anteroposterior and lateral diameters, and loss of the normal lordotic lines of alignment. A step-off of more than 3.5 mm in the anterior or posterior vertebral lines suggests ligamentous disruption with subluxation, facet dislocation, or burst fracture of the vertebral body. The presence of both anterior and posterior step-offs is diagnostic for burst fracture.

CT scan often reveals more severe comminution of fractures that appear as simple anterior wedge compressions on plain radiographs, and it should be performed when compression fractures are detected on plain films. All suspicious findings on the initial three-view C-spine series must be delineated further. Use of flexion–extension views for questions of alignment or ligamentous injury can reveal instability that was unsuspected on the initial lateral X-ray. CT scan of the cervical spine can examine regions of the spine that were poorly visualized on plain X-ray and delineate not only the exact extent of the fracture but also its effect on the spinal cord. However, CT scan is not reliable in looking for misalignment and purely ligamentous injuries. MRI is more valuable in visualizing soft tissue disruption in these situations.

Fractures of the Pedicles, Laminae, and Lateral Masses

The pedicles and laminae form a diamond-shaped bony encasement of the spinal cord. Isolated fractures of a single pedicle or lamina are usually due to penetrating injury, most commonly a gunshot wound. With blunt trauma, any combination of pedicle and laminar fractures can occur, depending on the angular or rotational forces applied in addition to hyperextension or, less commonly, hyperflexion. Displacement of pedicle or laminar fragments medially can result in direct spinal cord injury. Bilateral pedicle or laminar fractures render the spinal column unstable (Figure 7.25 A–C).

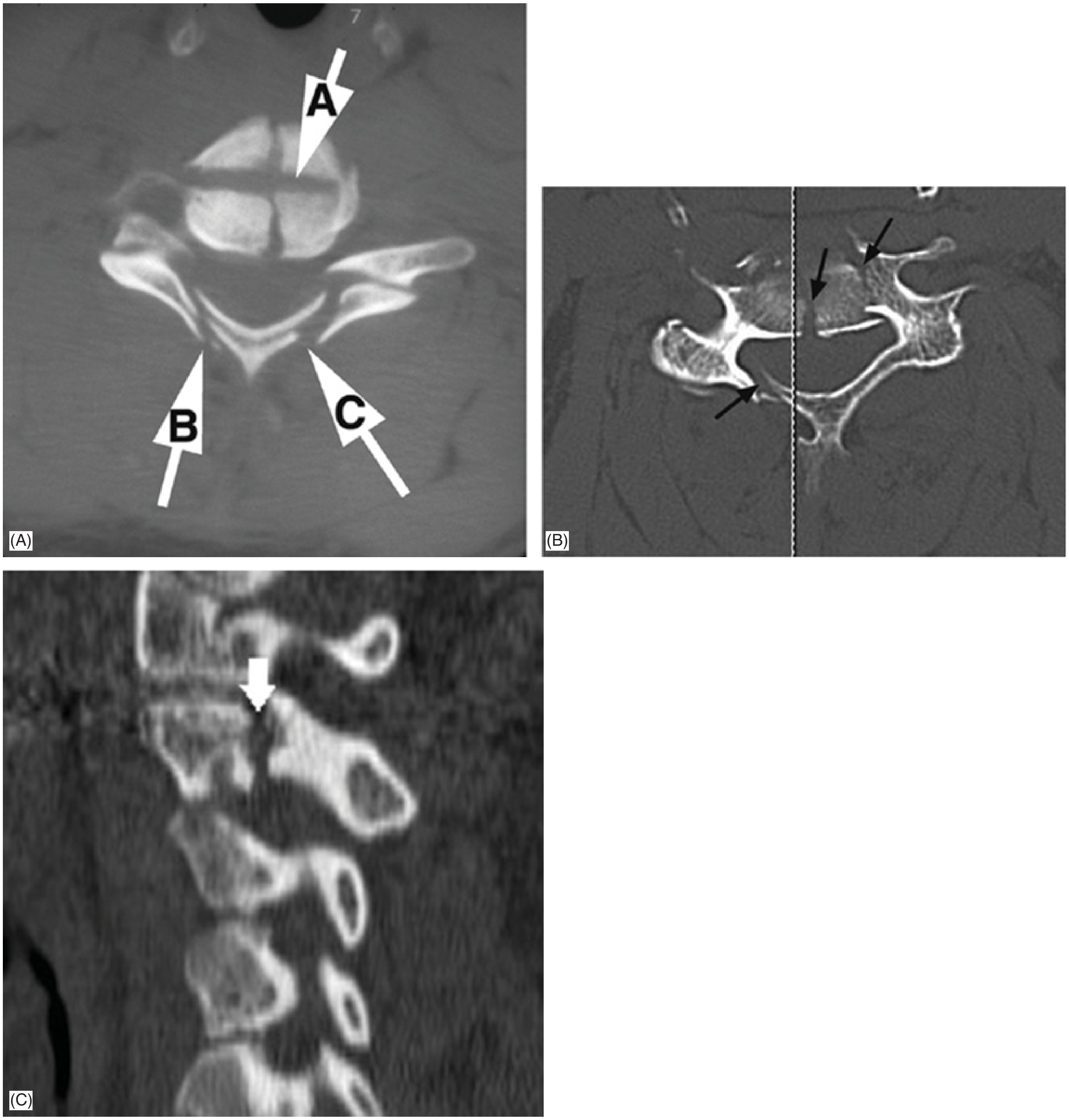


Figure 7.25 A–C CT scan showing a comminuted fracture of the vertebral body (arrow A) with fractures of both laminae (arrows B and C) in a patient who sustained an injury after diving into a swimming pool (A). CT scan showing a very unstable cervical spine fracture, involving the body and anterior and posterior arches of the vertebra (B). CT scan showing fracture of the pedicle (arrow; C).

The lateral masses represent the lateral articulations of the spinal column and contain the facet joints. They also form the bony margins of the neural foramina through which nerve roots enter and exit the spinal cord. Consequently, fractures of the lateral masses are often associated with nerve root injury.

Facet Dislocation

Facet dislocation may occur in isolation or associated with a fracture, and may be unilateral or bilateral. The majority of these injuries occur between C-4 and C-7 levels.

Unilateral facet dislocation results from forced flexion of the neck with a rotational component to one side or the other. If sufficient flexion or rotation occurs, one superior facet will become locked anterior to the inferior facet on that side. The opposite side will show normal alignment of the facets. Oblique X-rays of the spine will often more clearly demonstrate the dislocation. In approximately 25% of cases, there is an associated spinal cord injury. Reduction is accomplished by sedation and simple traction in most cases. Bilateral facet dislocation results from forced flexion of the neck, causing the superior facets to glide anteriorly on their inferior counterparts. Once the facet joints reach the peak of the inferior facet, they are said to be “perched” atop the inferior facet. If the superior facet continues anteriorly, it becomes locked in the dislocated position. Bilateral facet dislocation results in greater than 50% subluxation of the superior vertebral body on the inferior one and almost inevitably results in complete spinal cord injury (Figure 7.26 A–J).

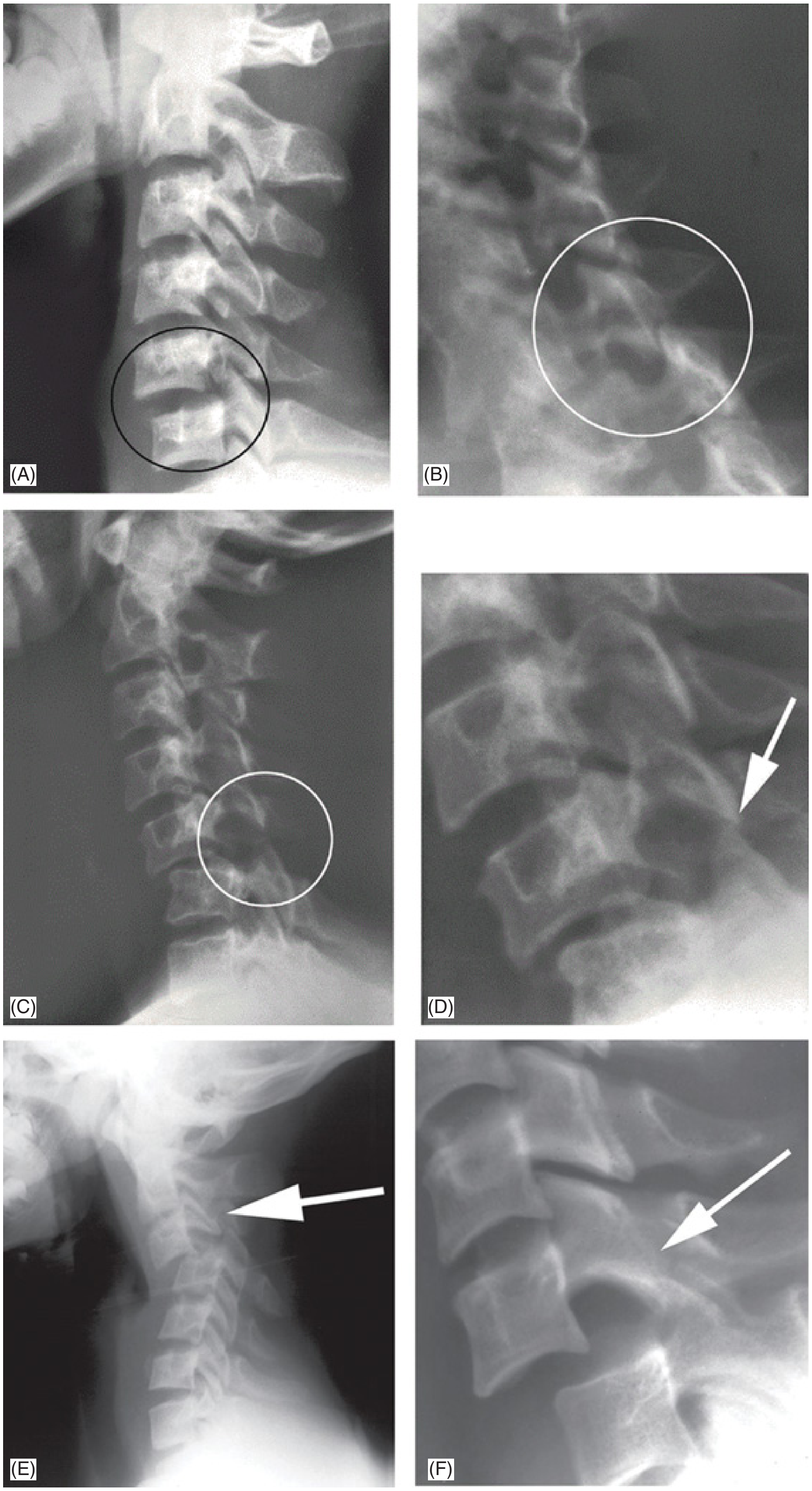


Figure 7.26 A–J Lateral X-ray of the cervical spine showing subluxation of C-5 on C-6 due to unilateral facet dislocation of C-5 (A). Oblique view of unilateral facet dislocation (B). Lateral X-ray of the cervical spine showing subluxation and angulation of C-5 on C-6 (C). Both superior facets (C-5) are seen resting atop the lower facets (C-6), a condition known as perched facets. Close-up view of perched facets (arrow; D). Lateral radiograph of a 15-year-old girl, injured while jumping on a trampoline, who arrived with quadriplegia. X-ray shows complete bilateral facet dislocation of C-3 on C-4 with significant anterior subluxation and angulation of C-3 (superior facets are lying anterior to the lower facets; see arrow; E). Close-up of bilateral facet dislocation (F). Schematic illustrating unilateral facet dislocation (G). CT scan showing left facet dislocation of the C-3 (H). Schematic illustrating abnormal angulation measurements with perched facets (I). Schematic illustrating anterior subluxation with perched facets (J).

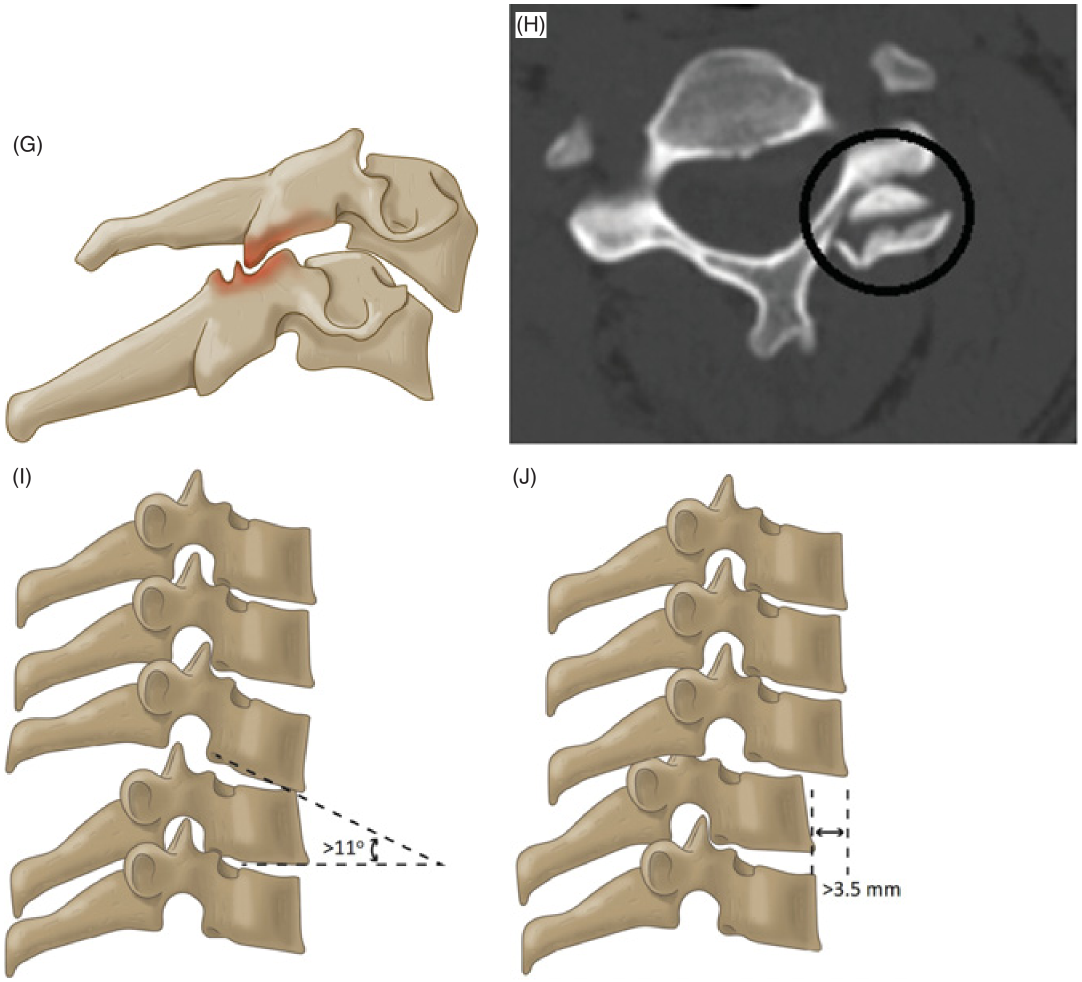


Figure 7.26 A–J (cont)

Cervicothoracic Spinal Injury

The junction of C-7 and T-1 is a relatively common location for spinal injury. Visualization of this area is difficult to accomplish in children, patients with large, muscular shoulders, and those with upper extremity injuries that make it difficult to pull on the arms for a lateral X-ray. Unless the lateral X-ray extends to the top of T-1, a swimmer's view is often required to verify alignment in this area. Detection of fractures with the swimmer's view is difficult because of superimposed bones and soft tissues, and CT scan has largely replaced plain X rays (Figure 7.27 A–C).

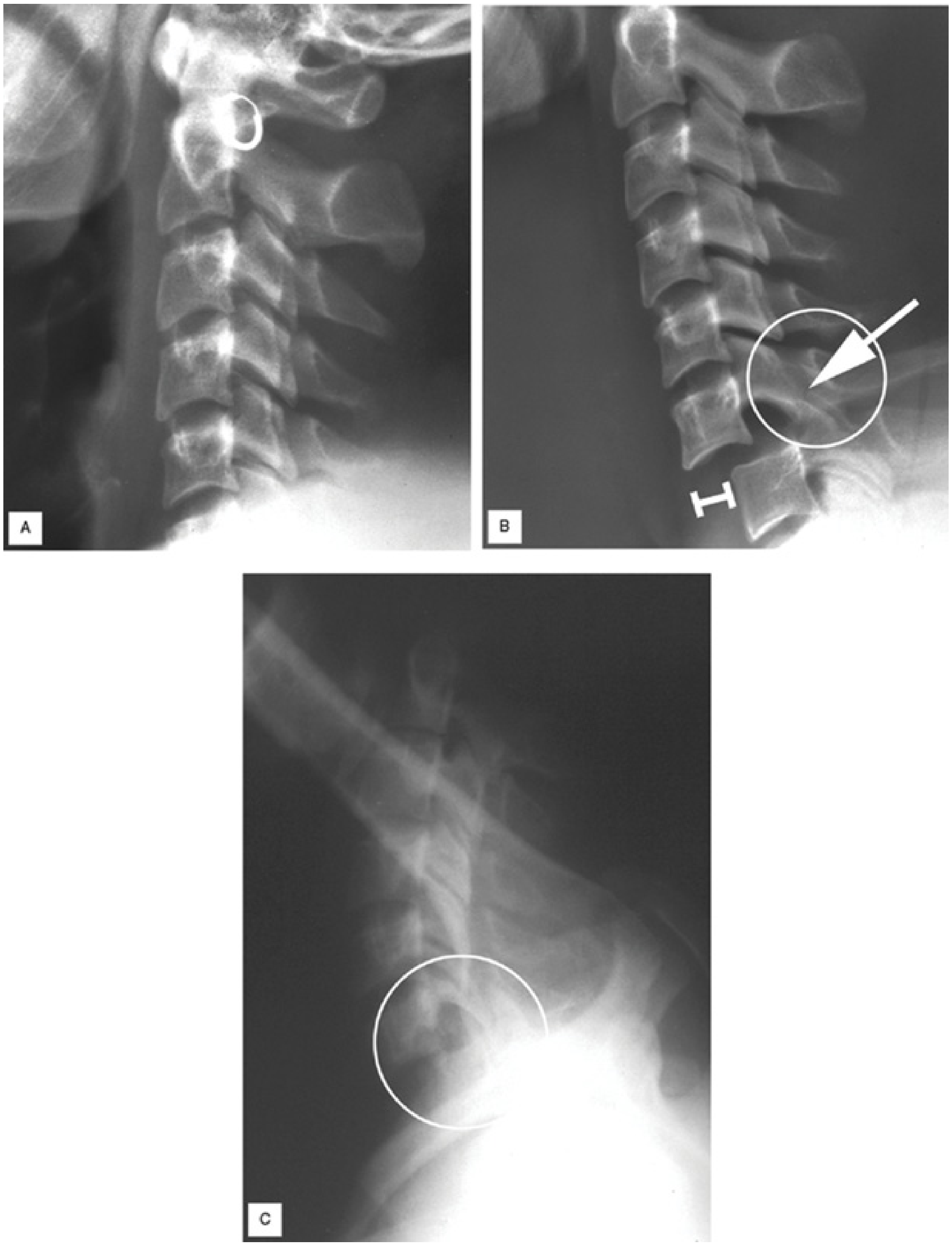


Figure 7.27 A–C Lateral cervical spine radiograph appearing normal to the top of C-6 level (A). Repeat lateral view of the same patient with a clearly apparent bilateral facet dislocation of C-6 on C-7 (arrow) and significant subluxation of C-6 on C-7 (B). Swimmer's view showing bilateral facet dislocation at the cervicothoracic junction (C).

Thoracic Spine Injuries

Unstable fractures of the thoracic spine are relatively rare because of the stabilizing influence of the ribs and their ligamentous attachments and protection by the large paraspinous musculature posteriorly and by the thorax itself anteriorly. In addition, the anatomy of the thoracic vertebrae inherently limits lateral movement and extension. Motorcycle collisions and falls from a height often result in thoracic spine injuries. Fractures in this segment of the spine are commonly associated with spinal cord injury because of the limited amount of space for the cord within the spinal canal in this area.

The chest X-ray often shows a widened upper mediastinum because of the presence of hematoma around the fracture. The radiological appearance is very similar to that in blunt trauma to the thoracic aorta (Figure 7.28 A,B).

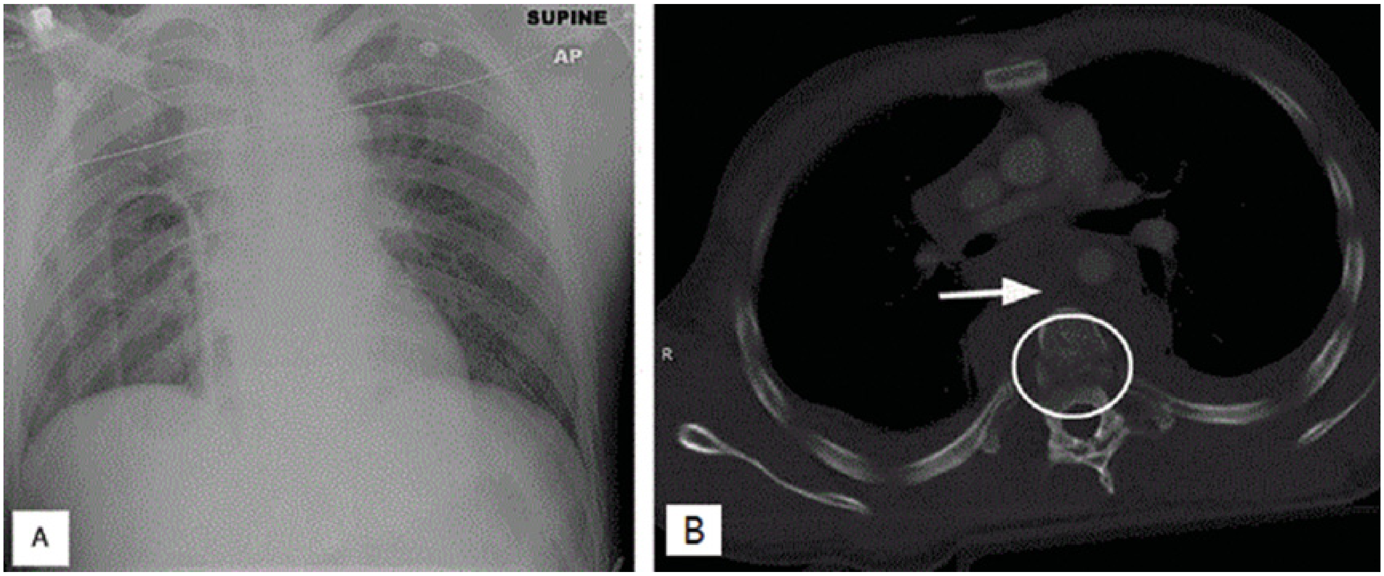


Figure 7.28 A,B Chest X-ray of a patient involved in a motorcycle collision shows a widened mediastinum (A). The differential diagnosis, besides thoracic aortic injury and fracture of the sternum, should include fracture of the thoracic spine. CT scan of the same patient shows a fracture of the thoracic spine (circle; B). Note the large hematoma around the fracture site (arrow).

Spinal instability is likely if there is a loss of >50% of the height of the vertebra. Compression fractures with an angulation >30 degrees and burst fractures with >25 degrees are generally considered unstable. The angle is measured by the intersection of the line of the superior aspect of the vertebral body one level above the fracture and the line along the inferior aspect of the vertebral body one level below (Figure 7.29, Figure 7.30, Figure 7.31 A–C).

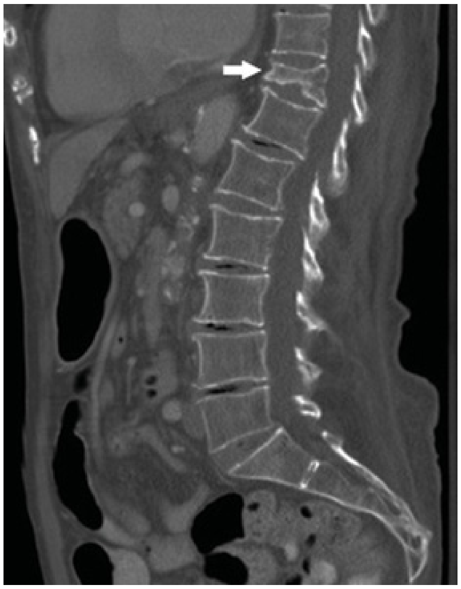


Figure 7.29 Anterior wedge compression fracture of the T-11, with a loss of >50 of the vertebra body height, indicating instability.

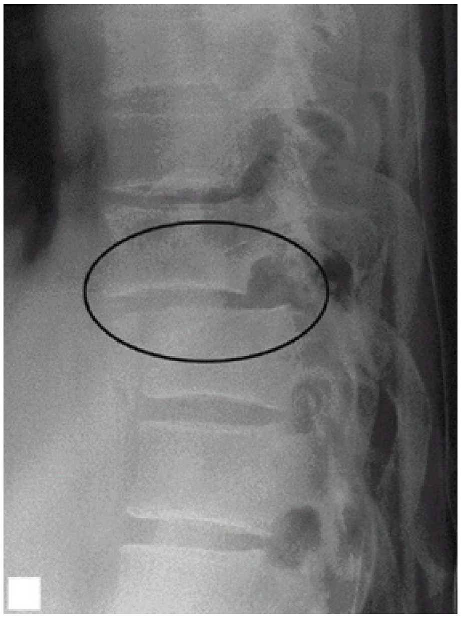


Figure 7.30 Fall from a height presenting with paraplegia at T-9. Plain radiograph showing compression fracture of T-10 with anterior subluxation of T-9 on T-10 and a small fracture of the anterosuperior aspect of T-10 body.

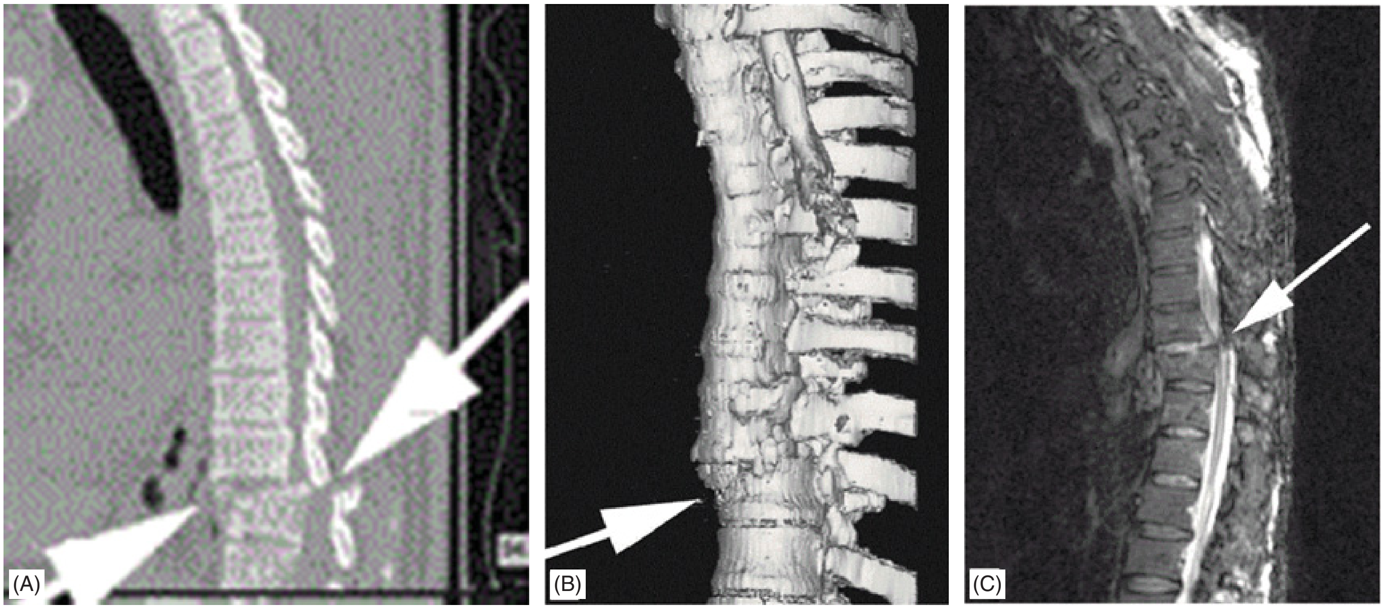


Figure 7.31 A–C Lateral CT scan reveals posterior displacement and impingement on the spinal cord, as well as fracture of the posterior elements of T-9 (A). 3-D CT scan reconstruction (B) and T2-weighted MRI (C) of the same patient showing severe compression of the spinal cord at the T-9–T-10 level (arrows).

Associated thoracoabdominal injuries may take precedence for stabilization, so it is important not to overlook the possibility of concurrent spinal injury.

Lumbar Spine Injuries

Lumbar Compression Burst Fractures

Compression fracture of a lumbar vertebra is one of the most common spinal fractures. It occurs in two distinct age groups. The first group is the elderly, in whom anterior vertebral body collapse can occur with relatively minor trauma and often signals underlying bone pathology, such as advanced osteoporosis or metastatic lesions. The second group is made up of younger patients who sustain severe hyperflexion of the lumbar spine, usually during a fall from a height. In these patients, associated injuries, such as calcaneal, acetabular, and other lower extremity fractures, mesenteric or renal arterial injury, aortic avulsion, and additional spinal column injuries, are common.

Lumbar compression fracture occurs as a result of acute hyperflexion at the waist, resulting in an anteriorly wedge-shaped vertebral body. The posterior wall of the vertebra is intact, and spinal cord injury is very rare. Collapse of more than 30% of the anterior height may result in progressive collapse of the vertebral body and increasingly severe kyphosis. Consequently, fractures with greater than 30% anterior compression are treated more aggressively. Paralytic ileus is commonly associated with these fractures. Radiographically, these fractures appear wedge-shaped with loss of anterior vertebral height on the lateral view. The presence of a burst fracture should be suspected if the anteroposterior view shows separation of the pedicles. This finding indicates a burst fracture rather than a wedge compression fracture (Figure 7.32 A,B, Figure 7.33 A,B, Figure 7.34 A,B).

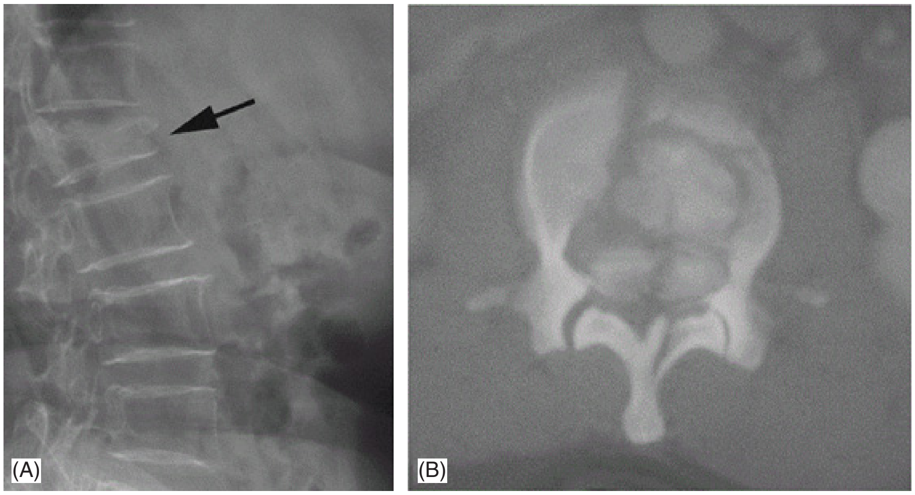
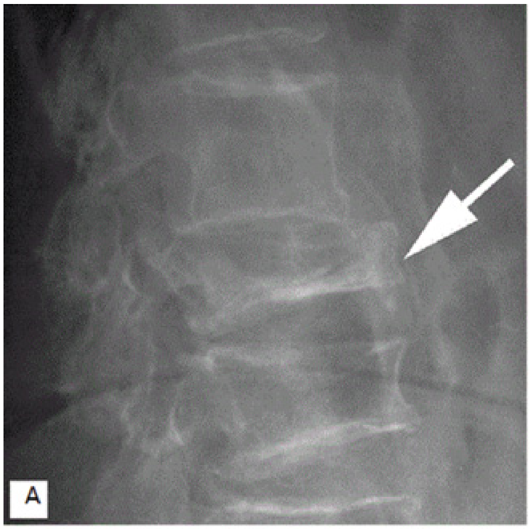


Figure 7.32 A,B Lateral X-ray of the lumbar spine of a suicidal patient who jumped out of a hospital window (A). It shows an anterior wedge compression fracture of L-1 (arrow). CT scan of the same patient (B). The L-1 vertebral body shows a comminuted fracture with intrusion of bony fragments into the spinal canal.



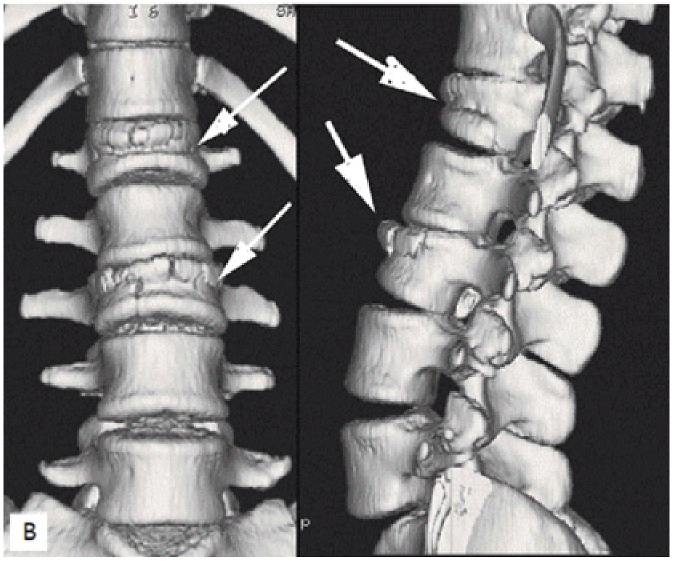


Figure 7.33 A,B Trauma victim fell from a height. Lateral X-rays of the lumbar spine showing severe compression fracture of L-1 (arrow) and less severe fracture of L-2 (A). 3-D CT scan reconstruction showing anterior wedge compression fractures of L-1 and L-3 (arrows) on the anterior and lateral views (B).

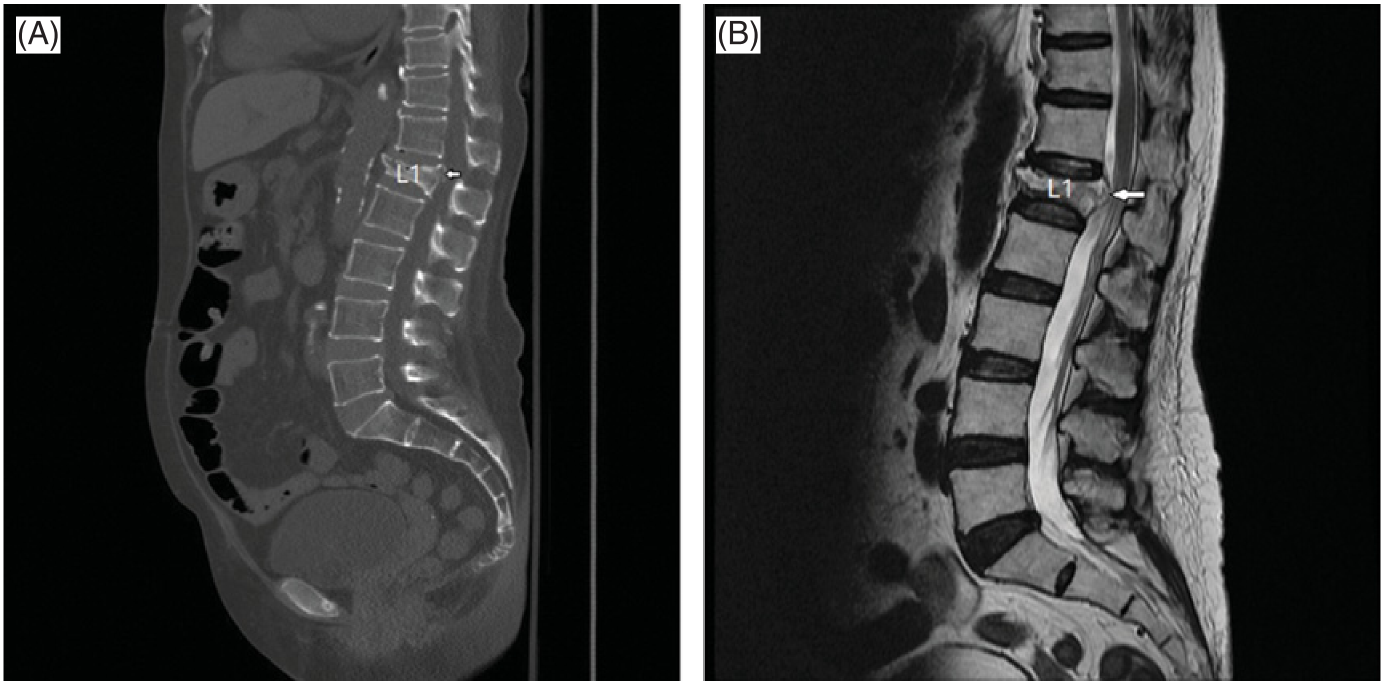


Figure 7.34 A,B Compression burst fracture involving the L1 vertebral body with a retropulsed fragment (arrow; A). MRI showing the severe compression and retropulsion into the spinal canal (B).

The extent of fracture comminution may be underestimated on plain X-rays, and a CT scan of the affected vertebra often shows a more extensive fracture. Fractures of the transverse process, lateral mass, or vertebral body in the lumbar spine from L-2 to L-4 may be associated with renal injury. Assessment for the presence of abdominal or retroperitoneal organ injury is indicated by CT scan.

Chance Fractures

Chance fracture typically occurs to a passenger wearing a lap belt, when the car is involved in a front-end collision. The patient sustains acute hyperflexion at the waist around the axis of the lap belt. The normal flexion point of the spine is located in the center of the vertebral body. An improperly worn lap belt shifts the flexion point anteriorly and acts as a fulcrum that pries apart the vertebral elements from back to front. There are several variations of Chance fracture, depending on the course of the fracture line. For example, the fracture line may begin in the interspinous ligament and then enter bony elements, only to terminate in a disruption of the disk space. The impact on spinal stability is identical regardless of the exact course of the fracture because both posterior and anterior elements are disrupted. Consequently, this is an unstable fracture (Figure 7.35, Figure 7.36 A,B).

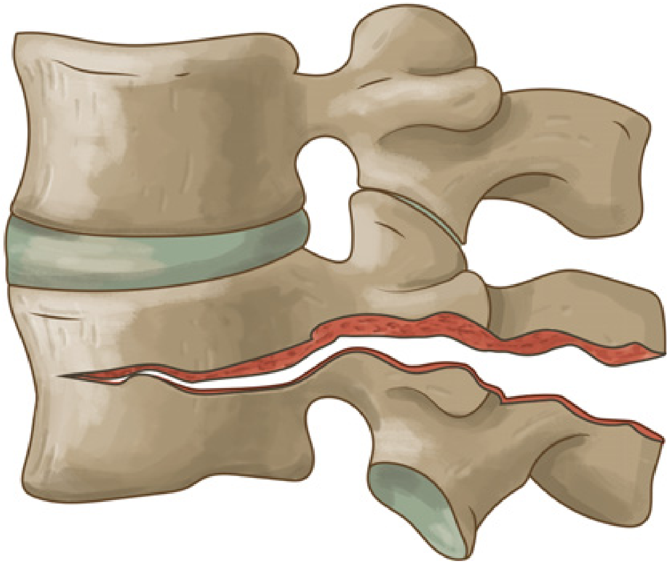


Figure 7.35 Schematic drawing demonstrating classic Chance fracture.

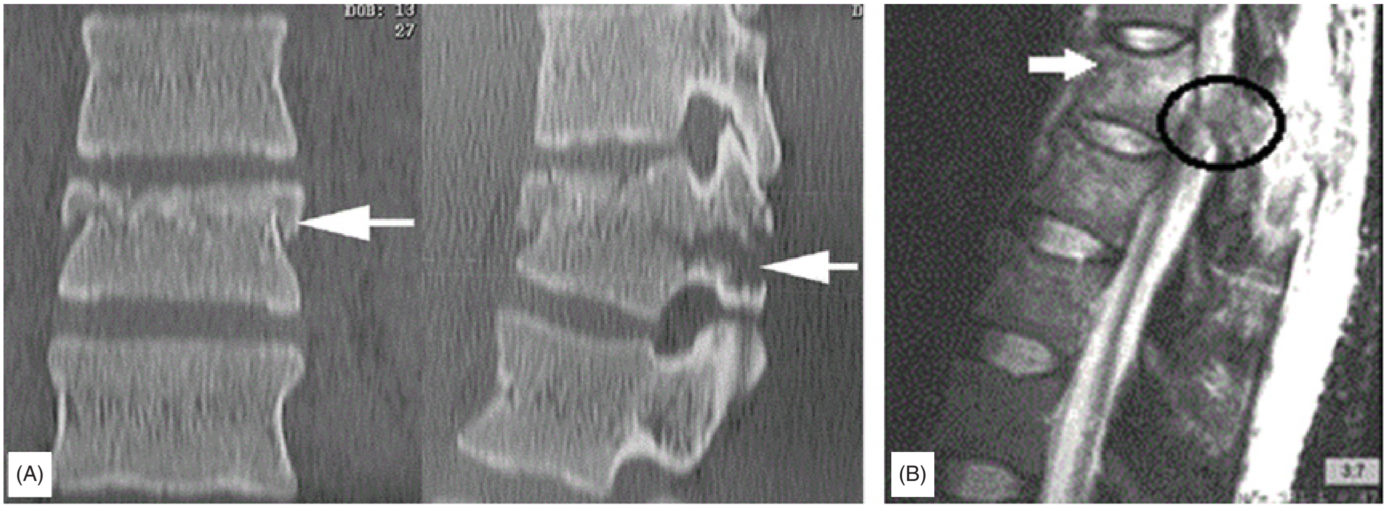


Figure 7.36 A,B Lumbar spine. CT scans showing a Chance fracture on anteroposterior and lateral views (A). T2-weighted MRI lateral view showing Chance fracture (arrow) with severe disruption of the posterior elements, as well as complete spinal cord compression and edema (circle; B).

Chance fractures are commonly associated with blunt intestinal injury, and patients should be investigated for this possibility. The presence of a seat-belt sign on the lower abdomen should alert the clinician to the possibility of Chance fracture as well as intestinal injury.

Fracture-Dislocation of the Lumbar Spine

The spinal cord ends at the level of L-1 or L-2 as the conus medullaris. Nerve fibers supplying the pelvis and lower extremities continue distally as the cauda equina. Injuries to the lower lumbar vertebrae may produce injury to this structure, resulting in the cauda equina syndrome. This syndrome is characterized by the presence of asymmetric weakness and numbness of the lower extremities, often with saddle anesthesia of the perineum, as well as sphincter dysfunction of bowel and bladder (Figure 7.37).

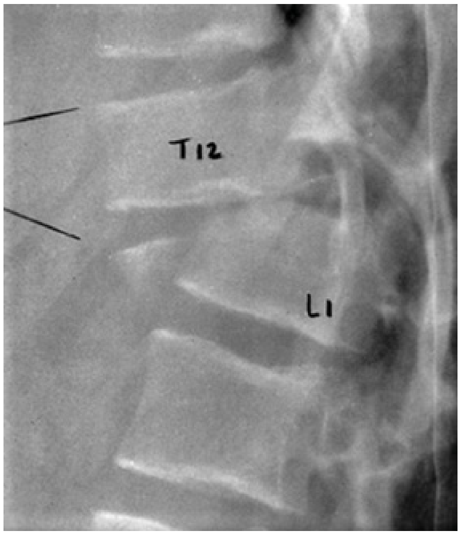


Figure 7.37 Lateral radiograph showing fracture– dislocation of T-12 on L-1.

Pediatric Spinal Injury

Cervical spine fractures are relatively rare in children because of the inherent flexibility of the pediatric spine. When spinal fractures do occur, the upper cervical vertebrae (C-1 to C-3) are most commonly involved.

The interpretation of spinal radiographs in children is difficult. Soft tissue thickness may vary considerably, depending on the phase of respiration. The presence of epiphyses makes the detection of fracture lines difficult. Incompletely calcified vertebrae cause vertebral bodies to appear wedge-shaped, suggesting possible compression fracture. Physiological anterior subluxation of C-2 on C-3 or C-3 on C-4 occurs in up to 50% of children and persists until mid-adolescence in 10% of patients. In the presence of apparent subluxation, drawing a line between the posterior spinolaminal line of C-2 through C-3 will demonstrate normal alignment if the spinolaminal line of C-2 lies within 2 mm of this line (Swischuk's line). Greater distances of C-2 from this line suggest true subluxation (Figure 7.38 A,B).

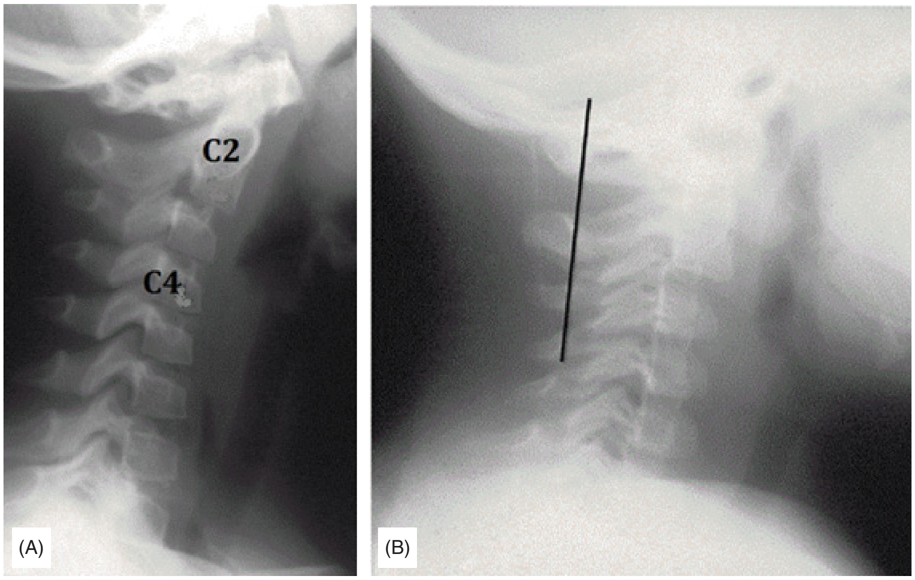


Figure 7.38 A,B Lateral cervical spine X-ray showing physiological subluxation of C-2 on C-3 (A). Lateral cervical spine X-ray showing alignment within Swischuk's line confirming that the subluxation is physiologic rather than pathologic (B).

It is often difficult to obtain adequate open-mouth views of C-1 and C-2 in children because of their small mouths and inability to cooperate. Consequently, it is often necessary to obtain a CT scan of the upper vertebrae, when the mechanism of injury or physical findings suggest the possibility of spinal injury (Figure 7.39 A,B).

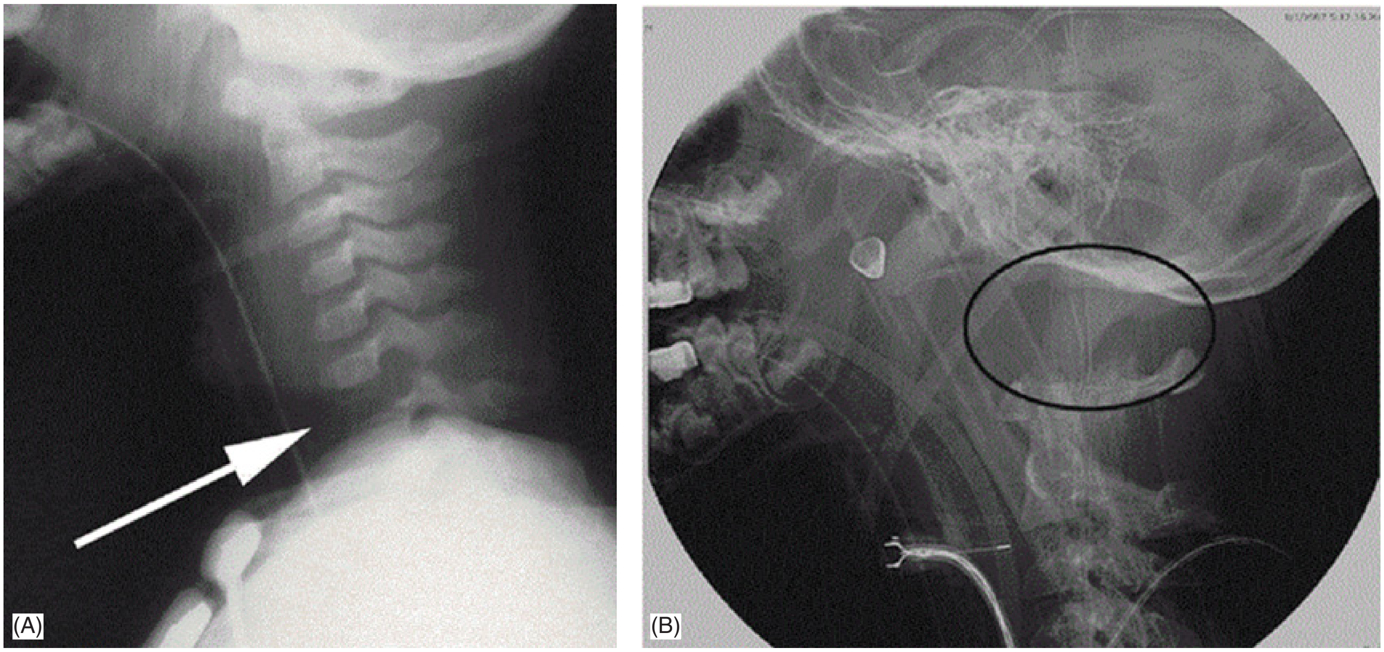


Figure 7.39 A,B Lateral cervical spine view of bilateral facet dislocation of C-6 on C-7 (arrow) in a young child (A). Lateral cervical spine of a 5-year old child showing atlanto-occipital dislocation (circle; B).

The syndrome of SCIWORA accounts for approximately one-third of spinal cord injuries in children younger than age 8 years. Symptoms may be delayed for many hours in a significant proportion of these cases. Consequently, obtaining normal radiographs of the spine and a normal neurologic examination at the time of injury does not necessarily exclude delayed spinal cord injury. The presence of any neurologic symptoms such as transient paresthesias at the time of injury requires investigation with either CT scan or MRI. Administration of high-dose steroids for spinal cord injury has not been well studied in children.

Penetrating Injuries to the Spinal Cord

Penetrating injuries account for a significant number of spinal cord injuries in the US. Most penetrating spinal injuries, including gunshot wounds, are stable. It is highly unlikely that victims of gunshot injuries, who are neurologically intact, have unstable fractures.

Stab wounds usually result in partial cord injuries and the prognosis is fairly good. However, the majority of gunshot wounds produce extensive cord damage and the prognosis is poor.

Many patients with penetrating cord injuries have associated serious injuries to the surrounding structures in the neck, chest, or abdomen. The clinical evaluation of the abdomen in a paralyzed patient is very difficult and unreliable. These patients should be evaluated with contrast CT scan. Patients with penetrating cervical or thoracic spinal cord injuries may need further investigation by means of endoscopy or swallow studies to rule out associated aerodigestive injuries.

The management of penetrating cord injuries is usually supportive and operative intervention has little or no role. In most cases, surgery to remove the bullet does not improve outcomes and may increase the risk of complications, such as infection, cerebrospinal fluid leak, and bleeding. However, some cases with incomplete cord injury due to gunshot wounds, especially if there is deterioration of the neurological function, may require surgical decompression. Similarly, victims with incomplete cord injuries and a missile lodged in the spinal canal may benefit from operative removal.

Steroids have no role for routine use in penetrating spinal cord trauma, and there is some evidence that they increase the risk of complications. In selected cases with extensive surrounding edema or shock wave injury due to high-velocity missiles, some physicians might give steroids (Figure 7.40 A, B, Figure 7.41 A,B, Figure 7.42).

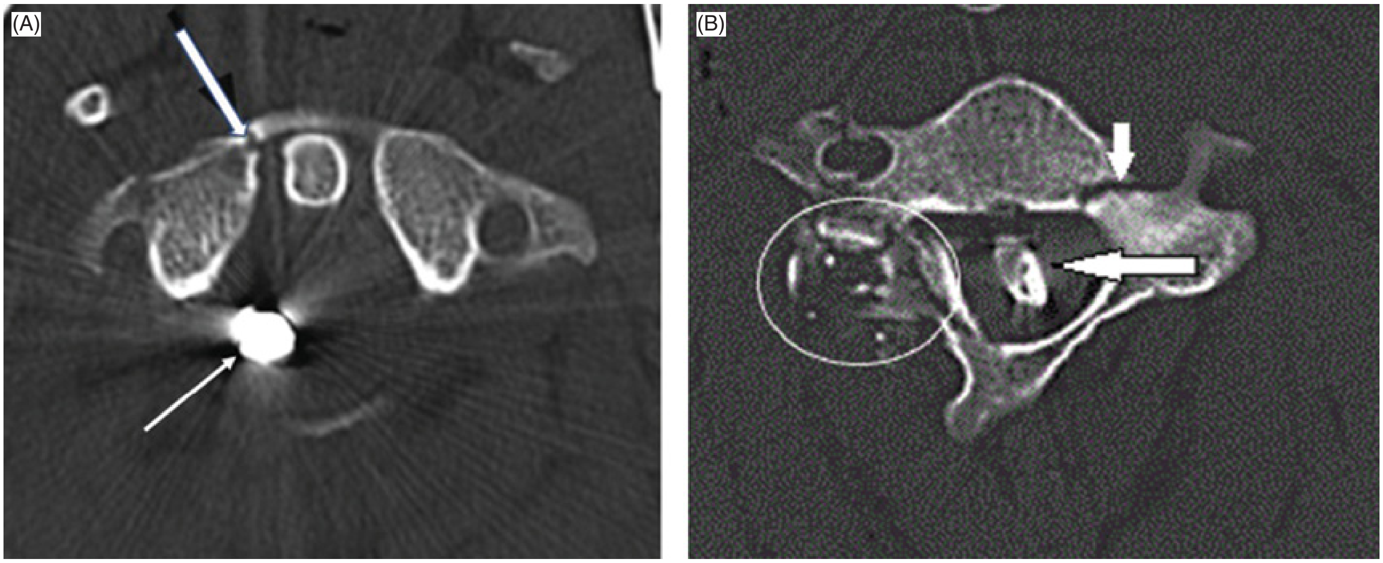


Figure 7.40 A,B Gunshot wound with fracture of the anterior arch of C-1 (thick arrow). The bullet is lodged in the spinal canal (thin arrow; A). Patients with complete spinal cord transection at this level die within a few minutes because of complete respiratory muscle paralysis. This patient, in addition to the quadriplegia, suffered severe hypoxic brain damage. Patient with a gunshot injury to the upper cervical spine, with fractures of the pedicle (small arrow) and the right lamina (circle) and the bullet lodged in the spinal canal (large arrow; B). This patient survived with permanent quadriplegia.

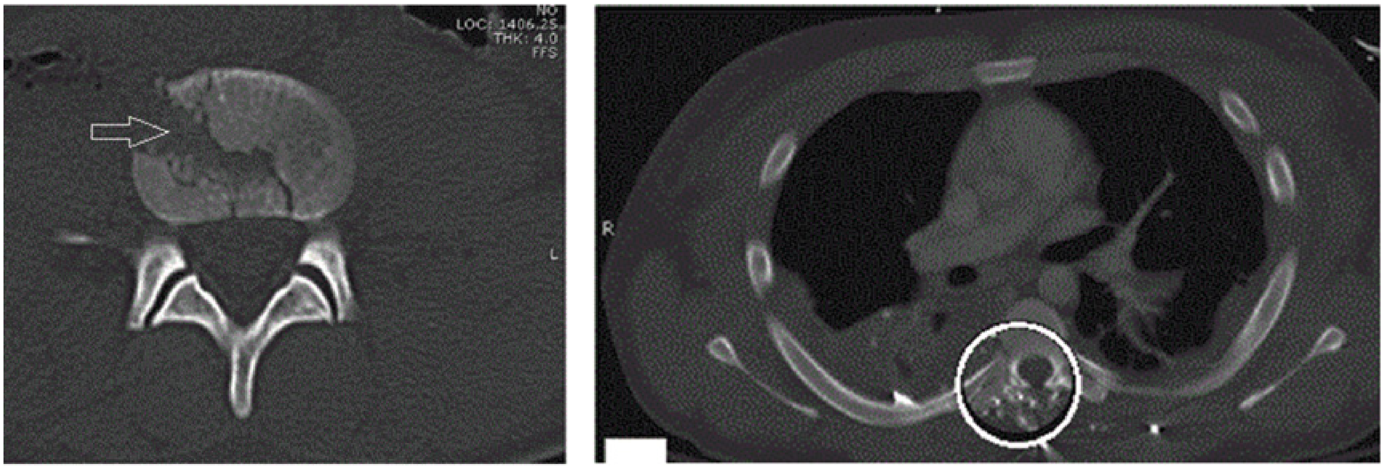


Figure 7.41 A,B Gunshot wound to the spine with extensive vertebral body damage but intact spinal cord (A). CT scan of patient with gunshot wound to the thoracic spine, showing extensive bony damage posteriorly but incomplete cord injury (B).

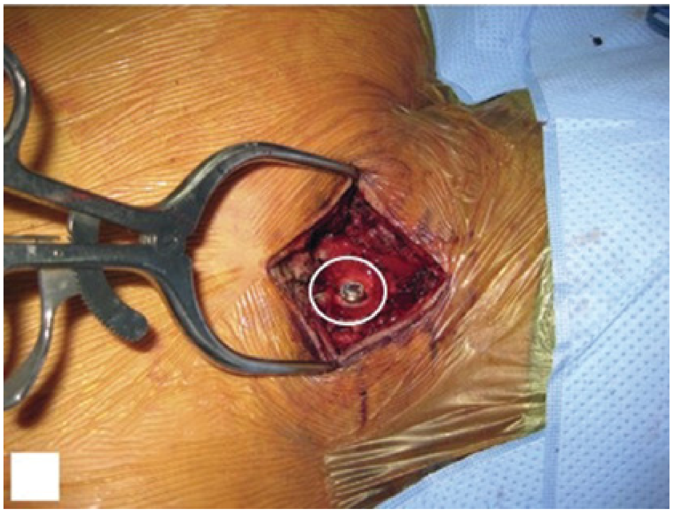


Figure 7.42 Intraoperative appearance of a bullet lodged in the intervertebral space (circle), causing partial cord injury with neurological deficits. In this situation, the bullet should be removed.

Chapter

8

Burn Injuries

Alexandra Lacey, Andrew Tang, Demetrios Demetriades, and Warren Garner

Introduction

The skin functions as a critical external barrier and serves a vital role in protecting against pathogens but also in thermoregulation, management of fluids and electrolytes, and protection from trauma. Small size burns cause relatively minor sequelae while larger burns can trigger a massive inflammatory response, secondary organ dysfunction, and result in death. The depth and extent of a burn will determine the severity of the response to this trauma.

Critical to decisions about the initial management include accurate assessment of the patient's burn wounds and associated injuries. Failure to accurately diagnose the type, extent, and depth of a burn will dramatically affect the patient's outcome. Current burn survival rates have continued to improve over the last several decades due to advances in surgical management and ICU care.

Clinical Examination

The initial assessment of a burn patient is similar to the approach for trauma patients. Use of the current Advanced Burn Life Support (ABLS) guidelines, which are similar to the ATLS guidelines, is strongly recommended. This follows a similar ABCs of the initial survey, followed by a secondary survey with a few special considerations. These are summarized as follows:

A– Airway – Initial management should include observations for possible inhalation injury and any difficulties with breathing. Cervical spine precautions should be maintained if there was concurrent trauma. If there was a significant smoke exposure, voice changes, or the patient is reporting changes in their voice, then laryngoscopy should be performed to assess for airway edema or soot on cords. If there is a positive laryngoscopic examination or clinically determined risk of airway occlusion, the patient should be intubated.

B– Breathing – High flow oxygen via a non-rebreather mask while should be given while the respiratory pattern is assessed. Circumferential burns to the chest or neck can cause restricted breathing and require early escharotomy to release the burn.

C– Circulation – Capillary leak syndrome after injury can result in significant loss of intravascular volume. To respond to this process, burn patients require two large bore peripheral IVs for access. If necessary, any lines can be temporarily placed through burn eschar. Circulation in circumferentially burned extremities requires an assessment of pulses.

Fluid resuscitation in patients with >20% total body surface area burns (TBSA) should have resuscitation started with lactated ringers at the following rates:

- <5 years – 125 ml/hr
- 6–13 years – 250 ml/hr
- >14 years – 500 ml/hr

D– Disability – Neurologic status and obvious deformities should be assessed. If the mental status is abnormal, this could be due to associated injuries, carbon monoxide poisoning, illicit substances, alcohol, hypoxia, or other medical conditions.

E– Exposure – All clothing, jewelry, and contact lenses should be removed to fully evaluate the burn. If a chemical burn occurred, all contaminated articles should be carefully removed and the wounds copiously irrigated with water. The entire body must be exposed to assess the burns. Cover the patient in clean dry sheets to help maintain core temperature if the provider is not going to manage the wounds. If the provider is going to be managing the wounds then an appropriate dressing can be applied.

Upon completion of the primary survey, a head to toe exam and an accurate assessment of the TBSA is completed. TBSA includes second- and third-degree burns (partial and full thickness). First-degree burns (superficial burns) are not included in the calculation for TBSA. When calculating the TBSA, it can be helpful to use the Lund-Browder chart or use the patient's hand to estimate the size of 1% TBSA on that patient (Figure 8.1).

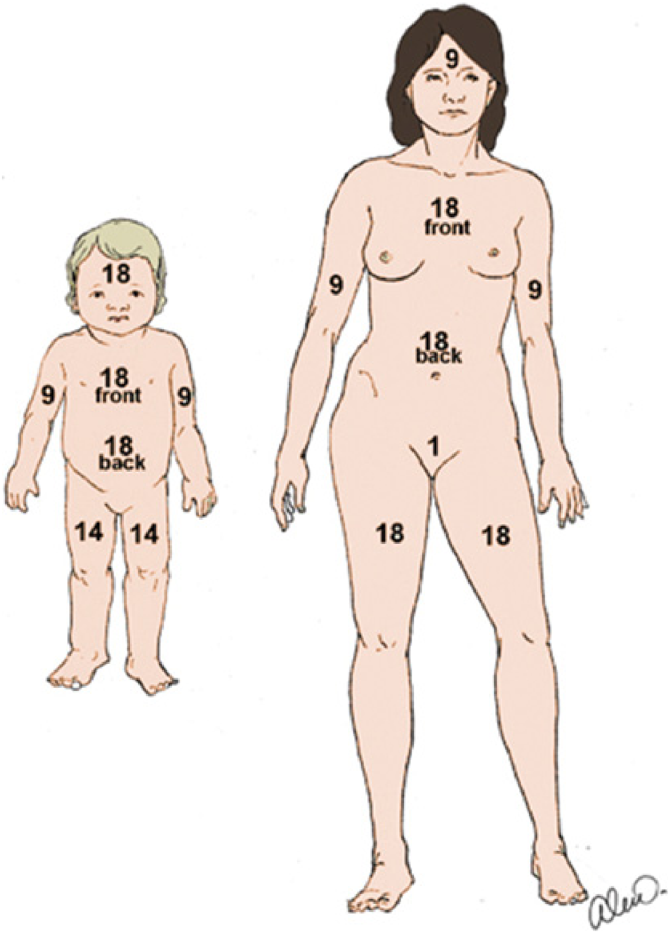


Figure 8.1 The "rule of nines" in determining total burn surface area in both adults in and children.

Investigations

The necessary tests and blood work for a burn patient is similar to a trauma patient with a few key additions. These include:

- Arterial blood gas – Early assessment of hypoxia is important for assessing for possible inhalation injury. Pulse oximetry may not be reliable in burn extremities due to swelling or burn eschar.
- Carboxyhemoglobin levels – Closed space fires can release large amounts of carbon monoxide (CO). CO has an affinity for hemoglobin forty times greater than oxygen and will falsely elevate pulse oximetry readings while causing tissue hypoxia.
- Trauma imaging – Up to 10% of burn patients will have concurrent traumatic injuries so it is important to assess for these.

General Management

Management of burn patients can take place over weeks to years, depending on the nature and long-term sequelae of the injuries. In this section, we will aim to focus on the first 24 hours of burn care, when the most important tasks are the burn resuscitation, wound management, airway/pulmonary management, and assessing if the patient requires transfer to a higher level of care.

In patients with a TBSA over 20%, there will be a significant total body inflammatory response to the insult resulting in massive vasodilation and capillary leak. Given this, large volumes of fluids are required to maintain intravascular volume and therefore tissue perfusion. This fluid is to be given in a sustained manner, and there should be a major focus on avoiding fluid boluses as these will increase peripheral and intra-abdominal edema. The American Burn Association recommends a total volume of fluids in the first 24 hours as follows:

- Adults and children >14 years – 2 ml lactated ringers × kg × % TBSA
- Children <14 years – 3 ml lactated ringers × kg × % TBSA
- Children <30 kg – 3 ml lactated rings × kg × % TBSA, plus D5LR at maintenance
- Electrical injury – 4 ml lactated ringers × kg × % TBSA

The fluid is to be given with half the volume over the first 8 hours after burn injury and the other half in the subsequent 16 hours after. This is a guideline, however; the most important facet of resuscitation is to adjust the fluids based on hourly urine output. In adults, the goal urine output is 0.5–1.0 ml/kg/hr, and in children (<14 years), the goal is 1–1.5 ml/kg/hr. If the urine output is under or over goal, then the fluids should be titrated by 10% each hour to meet the goal urine output.

Initial wound management includes cleaning the area of the burn with soapy water. In patients with large blisters (>1 cm), these blisters should be sharply debrided of the devitalized skin. The depth and size of the injury will determine the best dressing for the wound. Silver-based dressings, including silver sulfadiazine and other silver impregnated wound coverings, are very common due to their antimicrobial activity. Every medical center will have access to different dressings, and clinicians should make themselves comfortable with the dressings that they will have available for burn care.

In patients with circumferential full-thickness burns, there is a risk for developing a compartment syndrome. While edema progresses in the tissues adjacent to the burn and the rest of the body, the full-thickness burn does not stretch as normal skin would and instead acts like a tourniquet. The result is venous hypertension, then arterial occlusion, and finally tissue necrosis. In any patient undergoing resuscitation who also has circumferential full-thickness extremity burns, it is prudent to consider early escharotomy to avoid complications, as they are likely to develop compartment syndrome if not managed in a timely manner.

Pulmonary support of critically burned patients or patients with inhalation injury is critical in the initial 24 hours of their care. Inhalation injury can be caused by either superheated air or smoke causing thermal damage to the upper or lower airways and can also cause injury via the toxic products of combustion. A supraglottic injury will cause voice changes and difficulty breathing early in the patient's course as upper airway edema narrows their airway. This can be assessed with direct laryngoscopy. Any evidence of soot or airway edema necessitates early intubation to prevent an airway disaster as the swelling progresses. A subglottic injury will cause impaired ciliary action, sloughing of respiratory epithelium, severe inflammation, and significant ventilation-perfusion mismatch in the coming hours to days after injury. This injury should be treated with aggressive suctioning, aerosolized N-acetylcysteine, heparin, and albuterol along with advanced ventilatory strategies, which will be discussed further in this chapter.

When seeing patients with massive burns, it is important to consider if the burn wound is survivable. Using the modified Baux score, a rough approximation of survivability can be assessed. This method adds the TBSA of the burn plus the patient's age, plus an extra 17 points if inhalation injury is present. A score of 160 has been shown to have a 100% death rate, and numbers approaching this have increasingly low chances of survival. A clinician must also include the patient's existing comorbidities, as there presently is no good model to include significant conditions such as renal failure, cirrhosis, heart failure, or COPD that will dramatically worsen outcomes. This model also has limitations in the extremes of age.

Lastly, the American Burn Association has created specific transfer criteria for burn patients. These criteria should be followed by all centers that do not house a burn treatment unit. Patients who qualify for transfer to a burn unit include:

- Partial-thickness burns that are over 10% TBSA
- Partial or full-thickness burns that involve sensitive areas including the face, hands, feet, genitalia, perineum, or major joints
- Full-thickness burns of any size and in any age group
- Electrical burns including lightening
- Chemical burns
- Inhalation burns
- Burns in a patient with significant comorbidities
- Burns in children if the center they presented to does not have adequate facilities for the care of children
- Burns in patients who will require interventions for their social situation, emotional state, or rehabilitation needs

Tips and Pitfalls

- Missed or delayed diagnosis of inhalation injury. These patients will progressively develop worsening airway edema and what could have been an elective intubation will become an emergency situation.
- Incorrect estimation of burn size. The entire body must be examined to accurately assess TBSA, and an age-appropriate Lund-Browder chart should be used. If using the "hand" to approximate 1% TBSA, be sure to use the patient's hand, not the practitioner's.
- Missed coexisting trauma. Up to 10% of burn patients will have coexisting trauma, and this may be overlooked in the setting of significant burn. Be sure to complete a standard trauma work-up in these patients.
- Missed or delayed diagnosis of compartment syndrome. Full-thickness burns that are circumferential are at very high risk of causing a compartment syndrome. These patients should have hourly neurovascular checks if an early escharotomy is not pursued.
- Inadequate fluid resuscitation. Underestimation of TBSA will result in inadequate resuscitation and lead to hemodynamic instability, kidney injury, and conversion of any partial-thickness wounds to full-thickness wounds.
- Overresuscitation. The use of fluid boluses and excessive fluid resuscitation not titrated to urine output will result in anasarca, ileus, pulmonary edema, conversion of partial-thickness burns to full-thickness burns, and dramatically increase the patient's risk of developing abdominal compartment syndrome.
- Inadequate analgesia and sedation. Burn patients require large volumes of sedation and narcotics to manage their pain adequately especially during dressing changes.
- Inadequate wound care. Failure to properly debride wounds and provide a moist antimicrobial dressing will result in infection of burns, causing conversion of wounds to deeper injuries and a worsened inflammatory response.

Extent of Burn Injury

Burn wounds are classically described as having three distinct zones of injury. The zone of coagulation is the most central area of the burn, which is irreversibly damaged and has no perfusion or chance of recovery. The adjacent zone of stasis is moderately damaged tissue that is perfused and has the ability to recover. This is the tissue that is most at risk for progressive necrosis, increasing the burn injury burden. The outermost zone of hyperemia is not injured but is inflamed from the release of proinflammatory signals from the zone of stasis. There is significant hyperemia in the area (Figure 8.2 A–C).

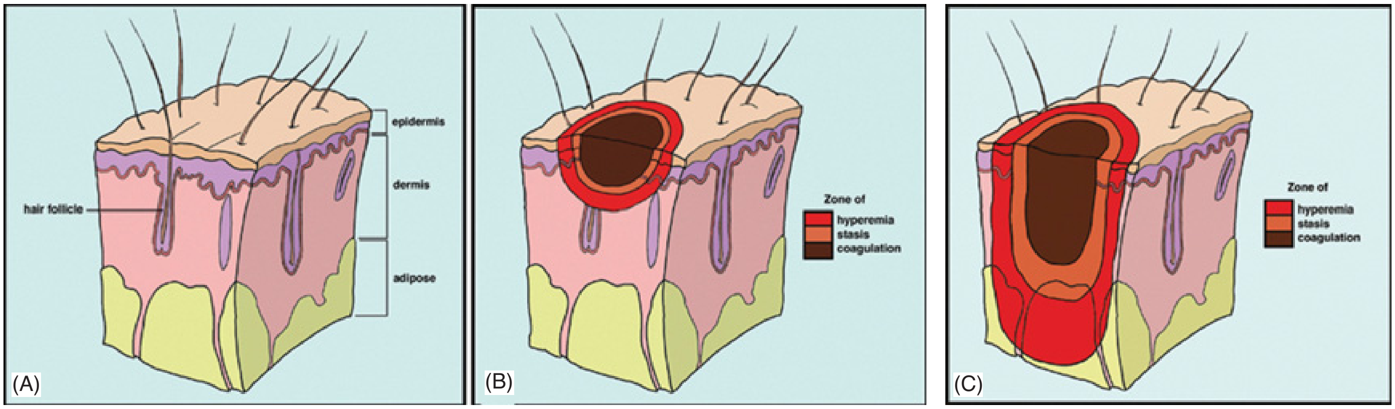


Figure 8.2 A–C Diagrams showing the normal skin anatomy and varying burn depth. Normal skin layers (A). Zones of injury in a superficial partial-thickness burn (B). The deeper elements of the skin remain uninjured and thus able to regenerate. Deep partial-thickness injury in cross section (C). The zone of necrosis extends deep into the dermis with the zone of stasis extending into the adjacent adipose.

Superficial Burns (First-Degree Burns)

A superficial burn is limited to the epidermis while the dermis and all elements of the dermal appendages remain intact. The burned skin is erythematous, painful, blanches with touch, but does not blister. It is similar to a casual sunburn. Skin regeneration typically happens within a few days as the damaged epidermal layer desiccates and sloughs off. Treatment is aimed at providing comfort with moisturizing lotion to create a supportive environment for healing. Pain control should include non-steroidal anti-inflammatory drugs or acetaminophen (Figure 8.3 A,B).

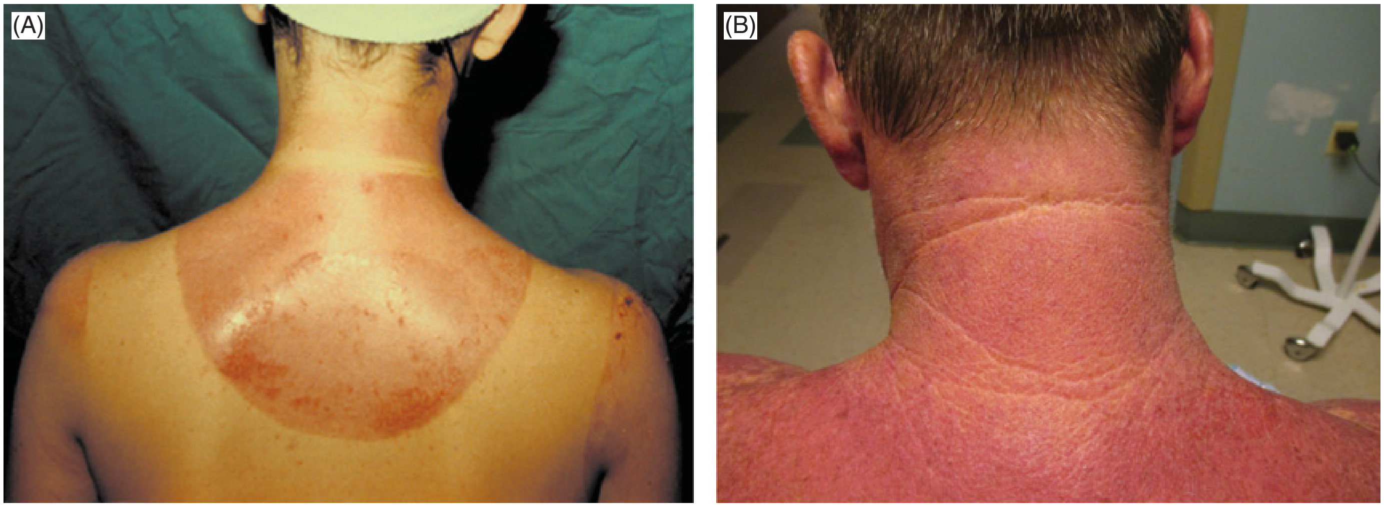


Figure 8.3 A,B Sunburn is a typical superficial burn (first degree). The skin is erythematous and painful but without blistering.

Partial-Thickness Burns (Second-Degree Burns)

Partial-thickness burns penetrate into the dermis and can be divided into superficial partial-thickness burns and deep partial-thickness burns. The depth of these burns greatly impacts the management and outcomes of this injury.

Superficial Partial-Thickness Burns

A superficial partial-thickness burn typically presents with large serous blisters and debridement will reveal an erythematous, painful, moist, and blanchable wound. With proper supportive measures, including a moist antimicrobial dressing and nutrition, these wounds will heal spontaneously with minimal if any scarring. Spontaneous reepithelialization takes place from the hair follicles, sweat glands, and rete ridges. Complete healing is typically seen within 14 days (Figure 8.4 A–D).

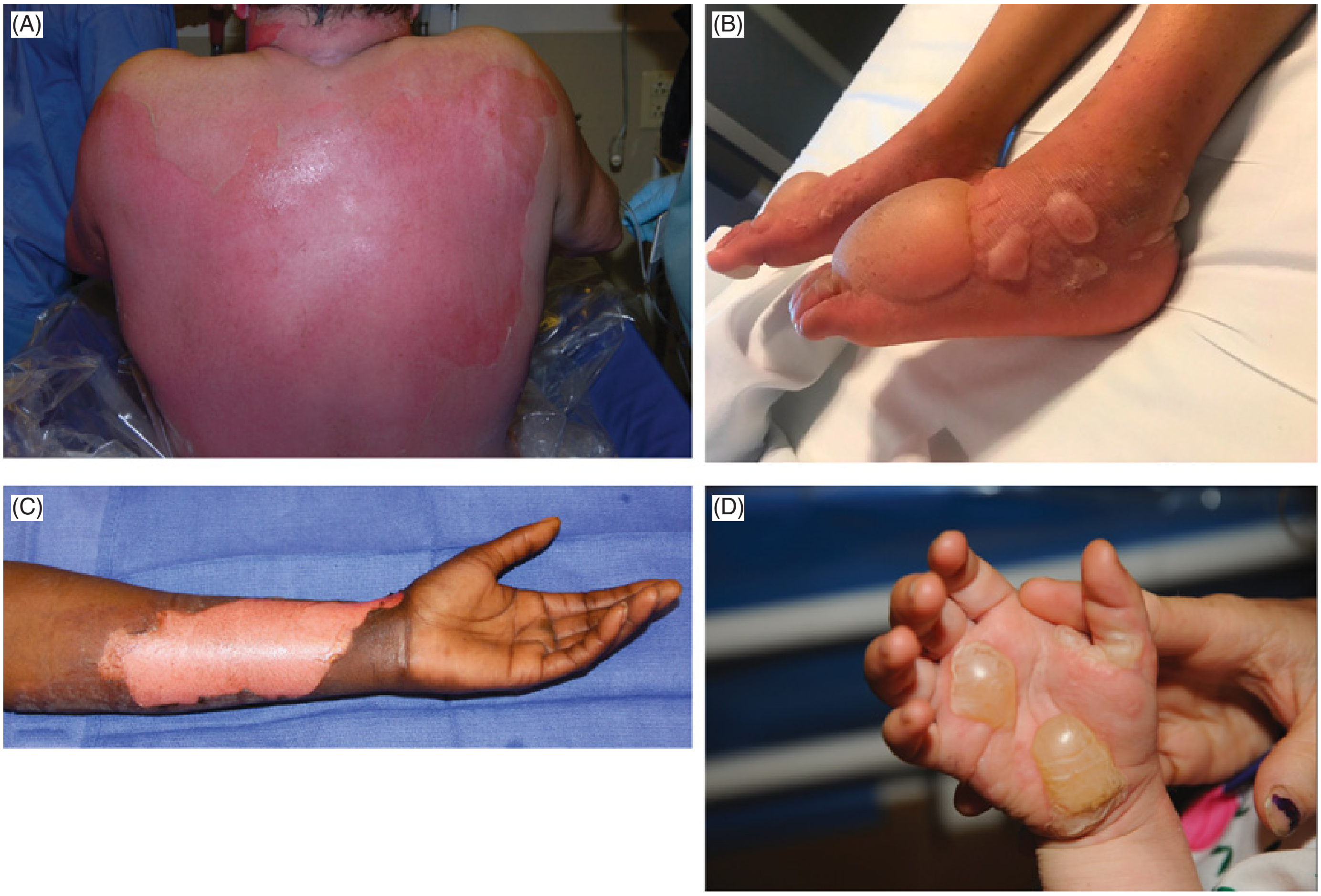


Figure 8.4 A–D Superficial partial-thickness burns. Superficial partial-thickness burn of the back demonstrating the characteristic pink moist tissue (A). Superficial partial-thickness burn of bilateral feet, with undebrided serous blisters, from scalding water (B). Superficial second-degree burn from radiator fluid scald on the forearm (C). The ruptured blisters had been debrided. Superficial partial-thickness burn of right hand, with characteristic blisters (D).

Deep Partial-Thickness Burns

A deep partial-thickness burn penetrate deeper into the dermis, resulting in significant damage to the appendages of the skin thus impairing the ability of the skin to re-epithelialize. These burns also are moist but can be less erythematous and less sensate than superficial partial-thickness injuries. These wounds require diligent antimicrobial dressings, adequate nutrition, and adequate perfusion to aid the recovery of remaining skin elements. Even in the setting of perfect support, these wounds often can require surgical excision and grafting to expedite wound closure (Figure 8.5 A,B, Figure 8.6 A,B).

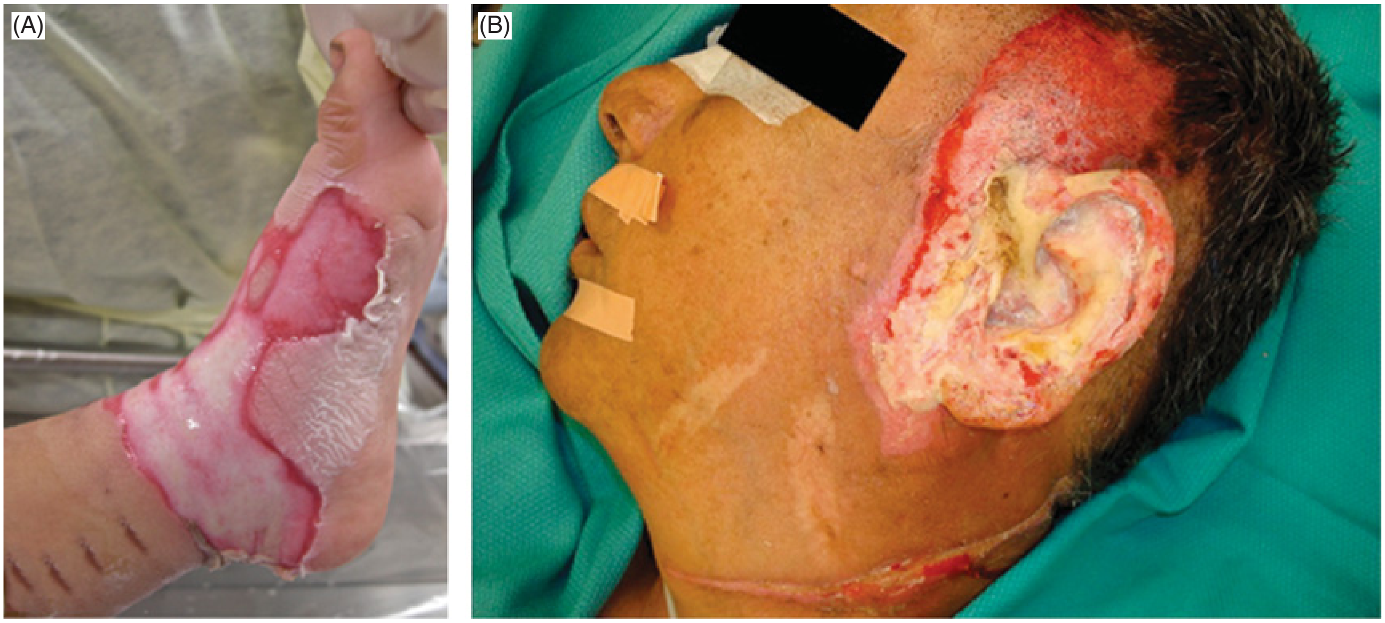


Figure 8.5 A,B Deep second-degree burn of the left foot from scald (A). Deep partial-thickness burn to the face with an area of full-thickness injury over the cartilaginous portion of the ear (B).

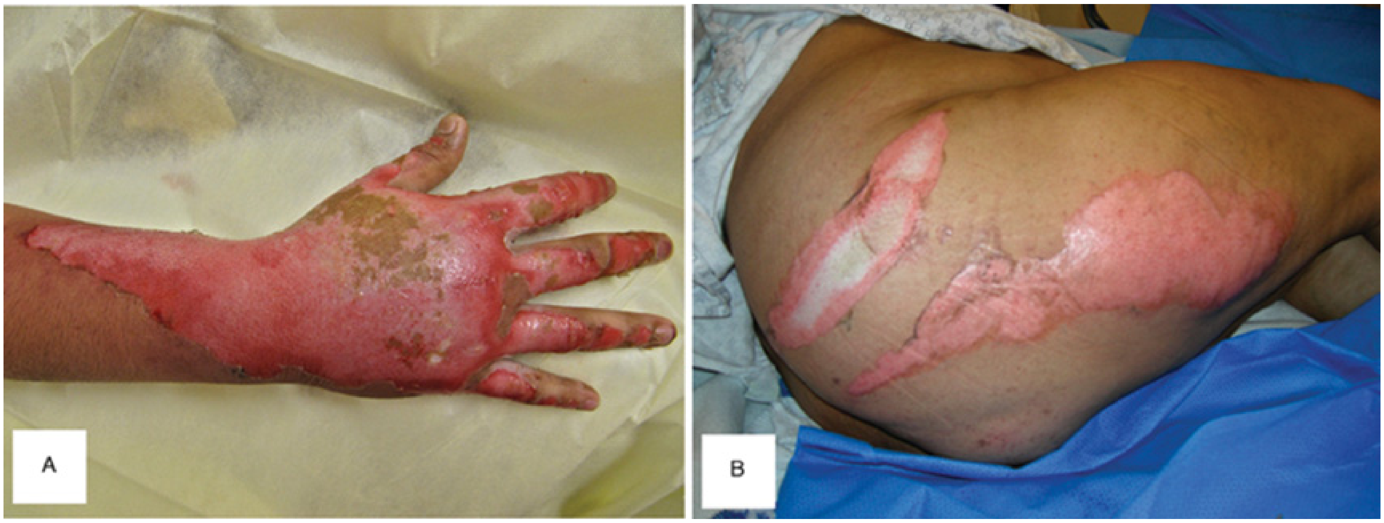


Figure 8.6 A,B Deep second-degree burns. Superficial and deep second-degree burn from hot-water scald to the hand (A). Deep second-degree burn with central third-degree burn. Notice the classic color differentiation (B).

Full-Thickness Burns (Third-Degree Burns)

When thermal injury extends through the entire dermis to the subcutaneous fat with destruction of the overlying epidermal and dermal elements, a full-thickness injury will result. Deeper injuries where fascia, muscle, and bone are also burned are referred to as fourth-degree burns, and these will require more extensive reconstruction. A full-thickness burn is insensate and appears leathery and dry (Figure 8.7 A–E).

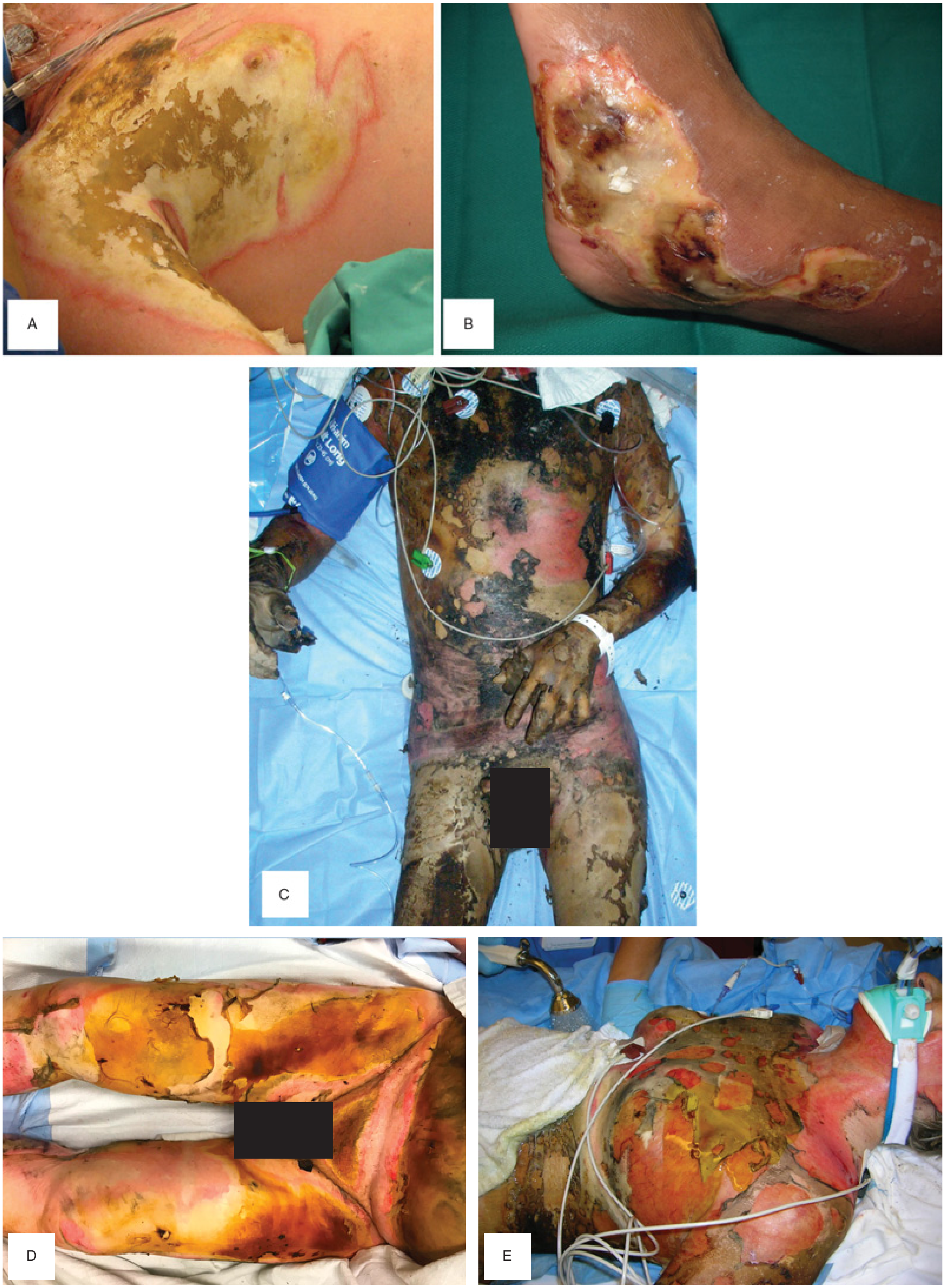


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Figure 8.7 A–E Third-degree burns. Third-degree burn with its characteristic leathery appearance and lack of tissue edema (A). Third-degree burn of the foot from hot cooking-oil splash (B). Fatal 95% TBSA third-degree burns (C). Full-thickness burn of the lower abdomen, genitals, and lower extremities from house fire (D). Note characteristic leathery appearance. Full-thickness burns of the anterior torso, neck, left shoulder, and upper arm (E).

If left untreated, third-degree burns will form a classic burn eschar that will separate from the surrounding viable tissue over the ensuing days to weeks. Spontaneous wound closure takes place by contracture formation from the wound edges as all regenerative elements within the wound bed are destroyed. In small wounds (<2 cm), allowing the wound contracture to proceed can be an option. However, in larger wounds, this would result in deformity and dysfunction. For these injuries, the mainstay of therapy is early excision with grafting.

Some authors describe fourth-degree burns as those with extensive thermal destruction of subcutaneous tissue, fascia, muscles, and bone. It is charred in appearance and requires extensive debridement, complex reconstruction, and in certain cases, amputation (Figure 8.8 A,B).

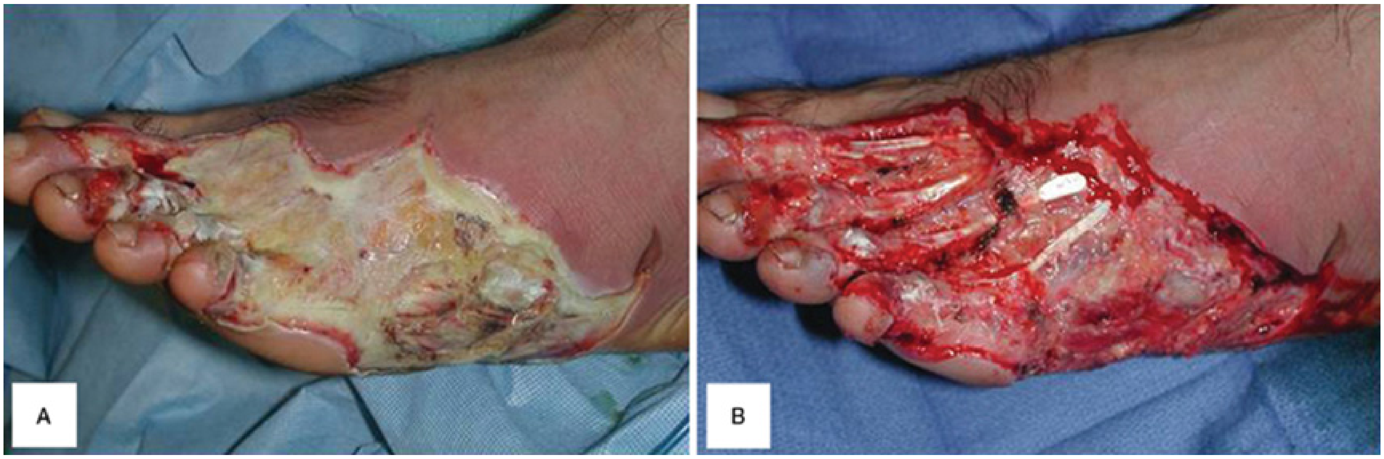


Figure 8.8 A,B Fourth-degree burn of the foot (A). Same patient after surgical excision (B). Note the exposed tendons and bone.

Excision and Grafting

The mainstay of burn treatment is removal of the nonviable burned tissue and either primarily closing the wound, if possible, or covering the debrided wound bed with a skin graft. The main method of excision of burn wounds is tangential excision (Figure 8.9). This process is performed by serially

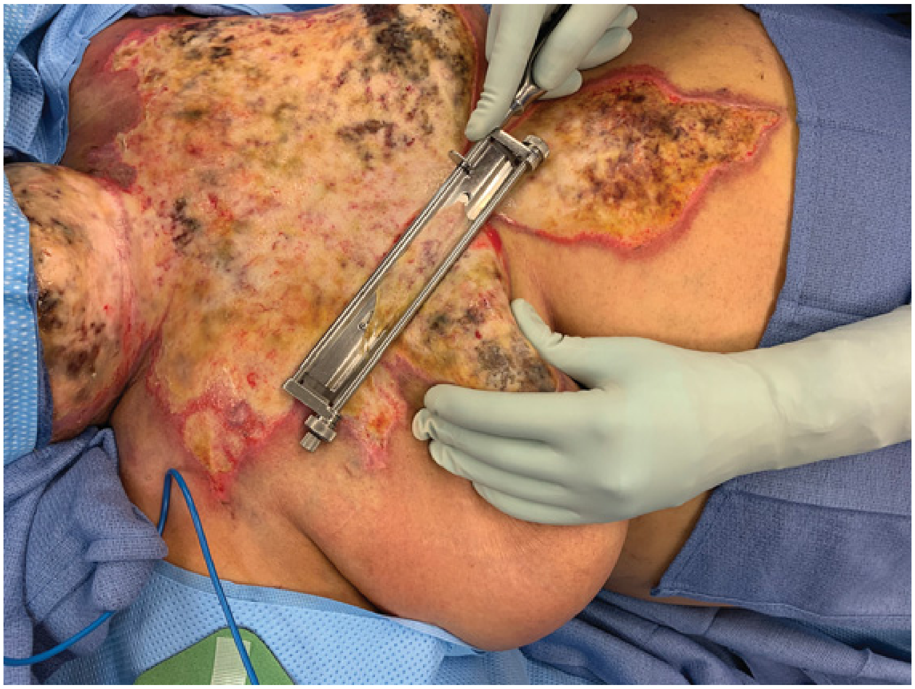


Figure 8.9 Tangential excision of a full-thickness burn wound on the chest using a Watson blade.

debriding the tissue using a blade until a healthy bleeding wound bed is encountered. Fascial excision (where all tissue above the level of the fascia is excised en bloc) is occasionally performed in critically ill patients who require rapid excision of their burn and who would not tolerate the blood loss associated with tangential excision. Once a healthy wound bed has been developed, the next step is autografting. Autografts are taken typically using a dermatome set to a depth of 0.008–-0.012 inches. The grafts can be meshed to allow a greater area of wound coverage or left as a sheet to allow improved cosmesis of the grafted area.

Special Considerations in Burn Injury

Inhalation Injury

Inhalation injuries typically occur in the setting of explosions or fires in enclosed quarters, and they are associated with a high mortality. The upper airway suffers from direct thermal damage up to the level of the glottis (supraglottic airway injury). The closure of the glottis and the moist airway environment limits the extent of thermal transmission distally. Toxic compounds of combustion, including hydrogen cyanide, ammonia, and aldehydes, propagate to the level of the alveoli and induce further chemical injuries that underlie the development of acute lung injury and acute respiratory distress syndrome (Figure 8.10 A–C).

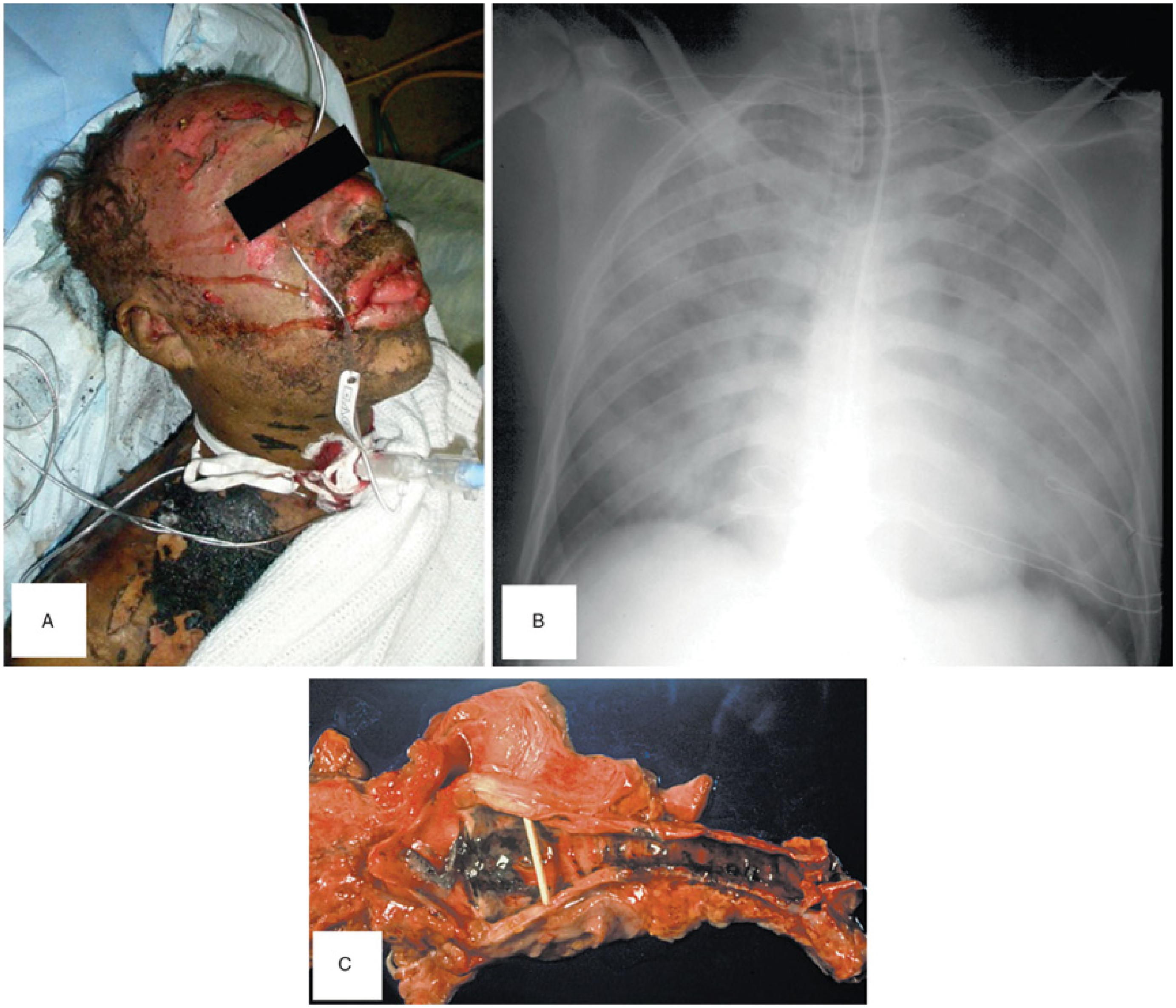


Figure 8.10 A–C Inhalation injury. Facial burn with singed facial hair in a man involved in a car fire (A). High suspicion for inhalation injury. This patient should undergo bronchoscopy. Chest X-ray demonstrating noncardiogenic pulmonary edema in a patient with severe inhalation injury (B). The laryngotracheal view of inhalation injury at autopsy (C). Note the extensive erythema and carbonaceous materials throughout the airway.

Clinical suspicion should be high in cases of fire within an enclosed space. Clues on physical examination include facial burns, singed nasal hair, carbonaceous sputum, stridor, and voice changes. Examination of the airway with laryngoscopy demonstrating mucosal erythema and edema accompanied by carbonaceous sputum is diagnostic of inhalation injury. There should be a low threshold for intubation if supraglottic injury is seen on direct laryngoscopy due to the progression of airway edema that can turn an elective situation into an airway emergency.

Currently, there is no reliable method to quantify the extent of inhalation injury. Bronchoscopy may help determine the extent of exposure, but no specific finding on bronchoscopy will correlate with severity of injury and length of intubation. Carbon monoxide poisoning may occur concurrently with inhalation injury, and a carboxyhemoglobin level should be checked on admission. Treatment is largely supportive with 100% oxygen (which shortens the half-life of carboxyhemoglobin from 4.5 hours to 50 minutes), mechanical ventilation, and aggressive respiratory care. High-frequency percussive ventilation (HFPV), based on the principles of delivering small stacked tidal volumes reduces barotrauma, facilitates airway clearance of mucous and debris. HFPV has been shown to improve oxygenation, decrease the incidence of acute respiratory distress syndrome, and improve mortality against historical controls. Additionally, aggressive pulmonary support should include nebulized albuterol, heparin, and N-acetylcysteine to aid in bronchodilation, mitigation of proinflammatory factors, and secretion clearance.

Abdominal Compartment Syndrome

Intra-abdominal hypertension (IAH) and abdominal compartment syndrome (ACS) can develop in critical burn patients as a result of excessive fluid resuscitation, injury-induced capillary permeability, and bowel edema. IAH is defined as a sustained elevation in intra-abdominal pressure ≥12 mmHg in adults or >10 mmHg in children. ACS is defined as a sustained elevation in IAP > 20 mmHg (>10 mmHg in children) that is associated with new organ dysfunction/failure. These can include a sudden decline in urine output, inability to tolerate tube feeds, and increasingly challenging ventilation due to limited diaphragmatic excursion.

Burns >30% and inhalation injuries are independent risk factors for ACS, and these patients should have their bladder pressures monitored routinely, by protocol. This complication progresses to multisystem organ failure and is uniformly fatal if left untreated. Alarming signs of ACS include a tense abdomen, increased ventilatory pressures, decreased urine output from renal vascular compression, and hypotension secondary to preload compromise from inferior vena cava compression. Laboratory values will demonstrate increasing lactate, rising pCO_2, and acidosis. Depending on the severity of the IAH, there are various therapeutic interventions for consideration, including:

- Escharotomies in abdominal burns
- Sedation, analgesia, and neuromuscular blockade in the appropriate cases
- Correction of any hypovolemia without excessive fluid resuscitation
- Decompression of the gastrointestinal tract with nasogastric and rectal tubes
- Drainage of any significant ascites when this condition is present
- Emergent decompressive laparotomy, which is the standard treatment for refractory ACS and should be performed rapidly if other interventions are failing (Figure 8.11)

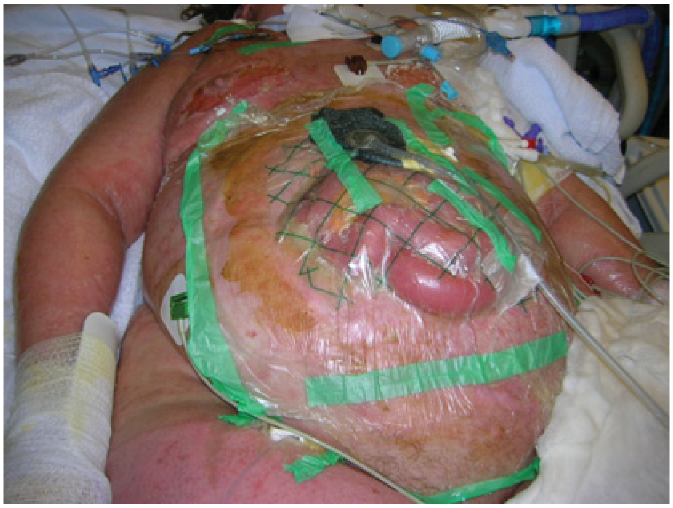


Figure 8.11 Decompressive laparotomy for abdominal compartment syndrome.

Circumferential Burns

A high index of suspicion for the development of compartment syndrome is key when taking care of patients with deep second-degree or third-degree burns of the extremities, thorax, or abdomen. Tissue and total body edema that accumulates under a constrictive burn eschar can ultimately lead to compromise in the perfusion gradient resulting in pressure and ischemia-induced neuromuscular damage, limb loss, and life-threatening compartment syndrome. All circumferential burns should have prophylactic escharotomy in patients undergoing large-volume fluid resuscitation. This should be done by a burn surgeon or communication should occur with a burn surgeon if performing these prior to transport.

Escharotomies are performed with electrocautery to limit blood loss. Incisions are made over the limb on both the medial and lateral aspects to achieve complete eschar release. The underlying osteofascial compartments should be examined for compartment syndrome, and if suspected, standard fasciotomies are performed.

Circumferential burns of the thorax may cause decreased chest wall compliance resulting in oxygenation and ventilation compromise. Thoracic compartment syndrome should be suspected if there are increased peak airway pressures, hypercarbia, and hypoxia. Properly performed escharotomies result in immediate improvements in chest wall compliance and improved arterial blood gas (Figure 8.12, Figure 8.13 A,B, Figure 8.14 A,B).

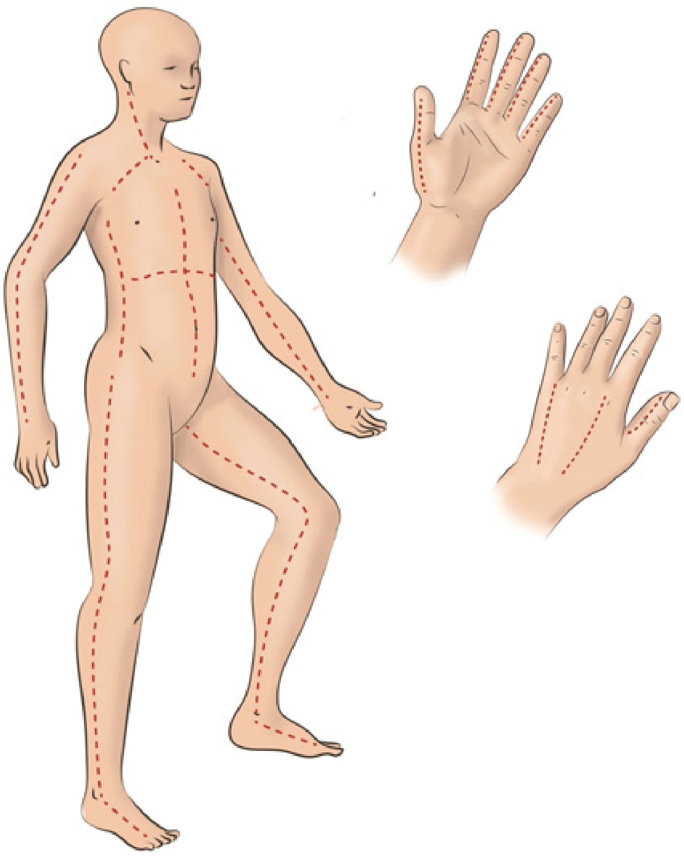


Figure 8.12 Escharotomy for circumferential burn. Illustration of the recommended escharotomy incisions.

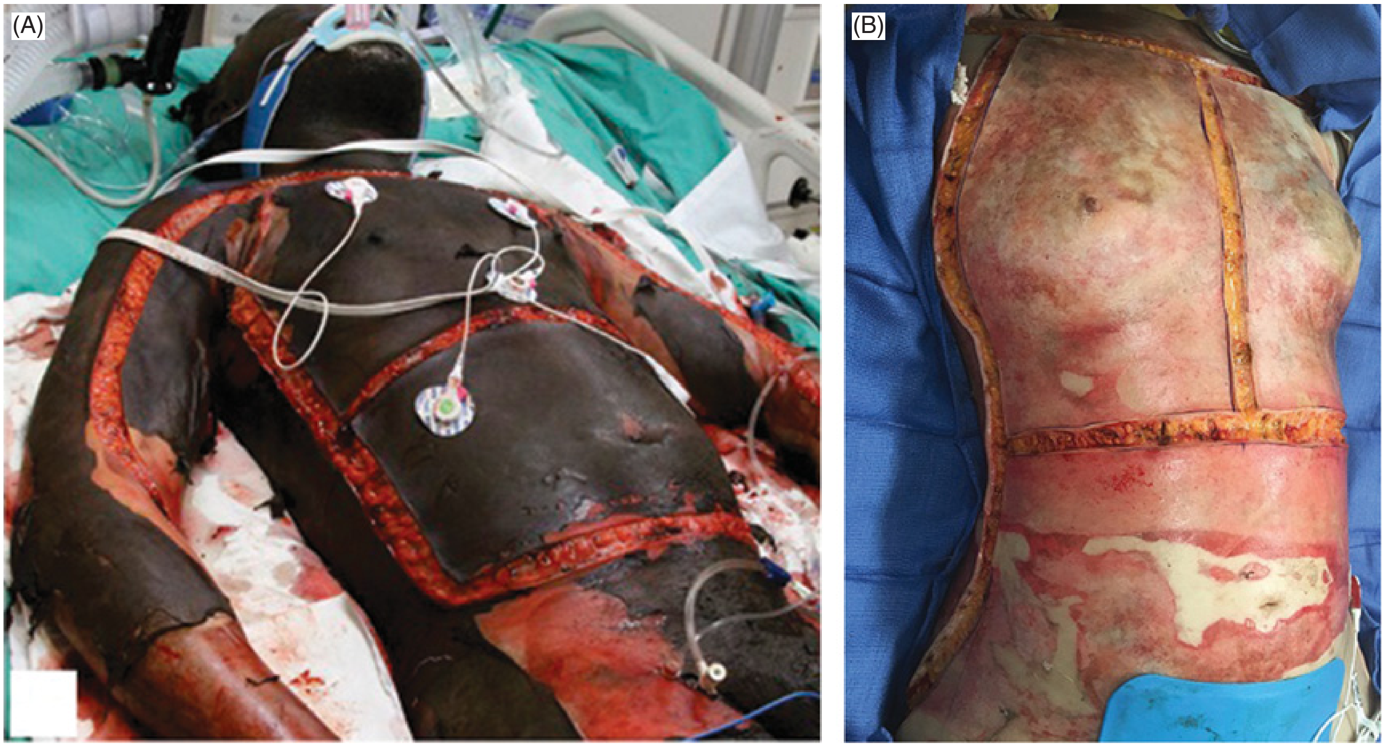


Figure 8.13 A,B Truncal and extremity escharotomies in for circumferential truncal and extremity full-thickness burns.

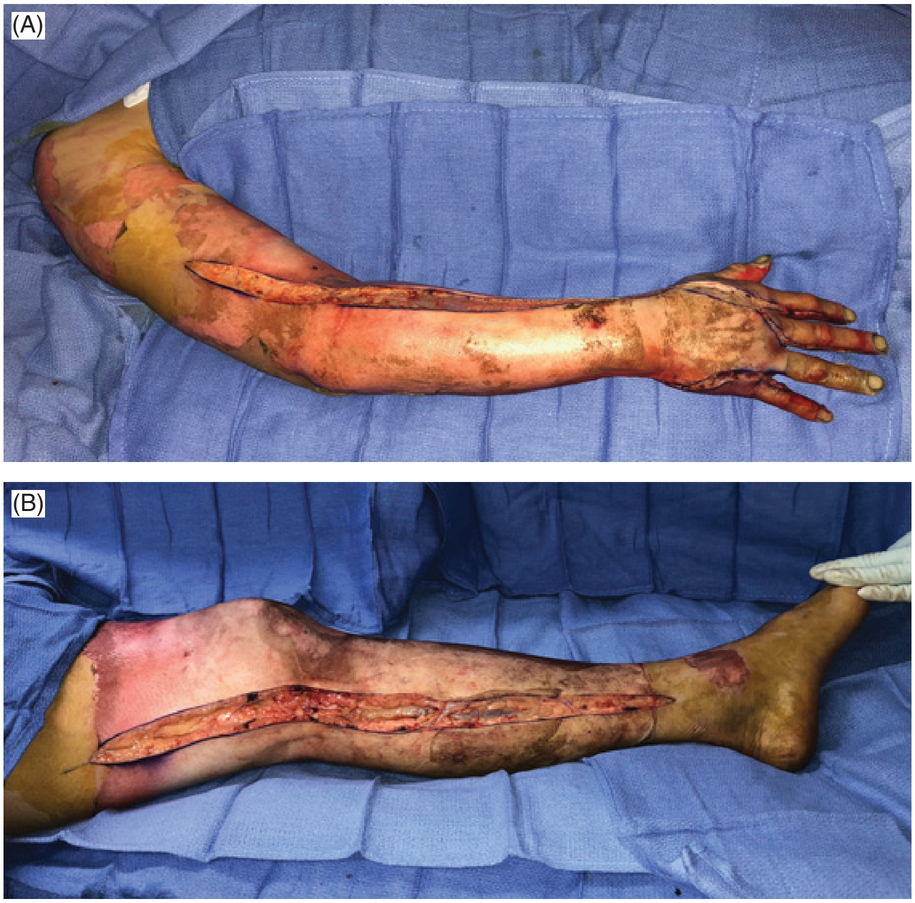


Figure 8.14 A,B Escharotomies for circumferential extremity burn. Circumferential deep second-degree burn requiring forearm and hand escharotomies (A). Circumferential burns of the lower extremity requiring escharotomies (B).

Scald Burns

Scald burns commonly result from hot water and mostly involve the elderly or young children. Water at 60°C can cause full-thickness burns in 3 seconds, and governmental regulations to lower hot water tank temperatures have led to a decrease in such injuries. Scalds on skin with light clothing tend to be worse than on exposed skin areas, as the clothing tends to retain heat. Similarly, thick soup and sauce also tend to cause deep thermal injury. Cooking oil and grease can reach 200°C and is another common cause of scald injury. Deliberate scald burns account for 10% of child abuse cases. Characteristic “immersion” patterns should promptly alarm the clinician of such possibility, and the case should be reported to appropriate agencies (Figure 8.15 A,B, Figure 8.16 A,B).

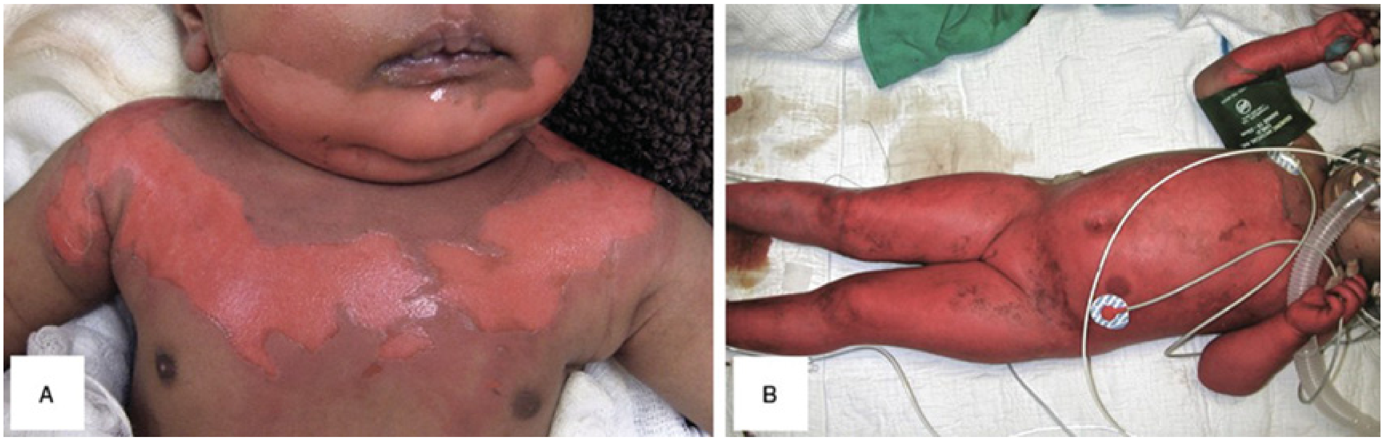


Figure 8.15 A,B Scald burns. Hot-water scald in a child abuse victim, by immersion into hot water.

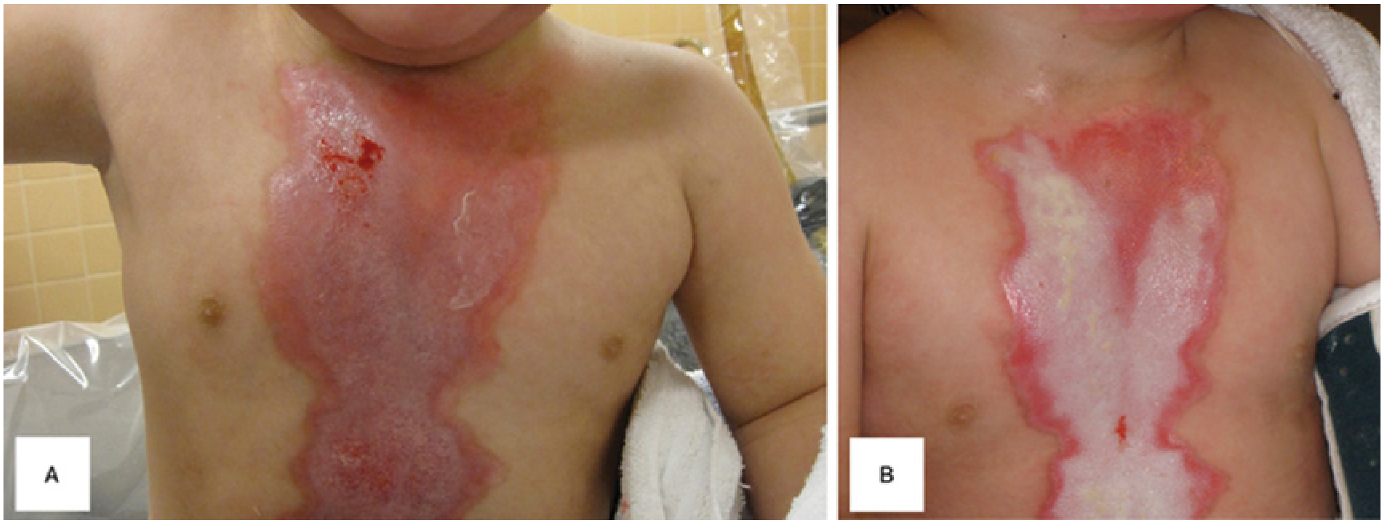


Figure 8.16 A,B Scald burns. Hot-milk scald in a child upon presentation (A). The same child 2 days after presentation (B). Notice the conversion of superficial to deep second-degree burn.

Chemical Burns

The primary concern with any chemical burn is to immediately remove the source and ensure no injury comes to care providers of the chemically burned patient. Any clothing contaminated with the chemical needs to be promptly removed and carefully handled. Exposed skin and mucus membranes need thorough irrigation for a minimum of 20 minutes. The degree of tissue destruction is dependent on the concentration, form of the chemical, pH, duration and volume of contact, and the extent of irrigation.

Alkali agents typically produce extensive damage via liquefactive necrosis, which can penetrate deeply below the skin or mucus membranes. The process will continue to denature proteins and saponify fats until all the alkaline substances have been neutralized by irrigation or host tissue if already penetrated. Acid injuries tend to be more superficial, as they cause coagulative necrosis that often will occur rapidly and on the surface of the affected tissue. The coagulum caused by this process will halt and further penetration or tissue damage (Figure 8.17 A,B).

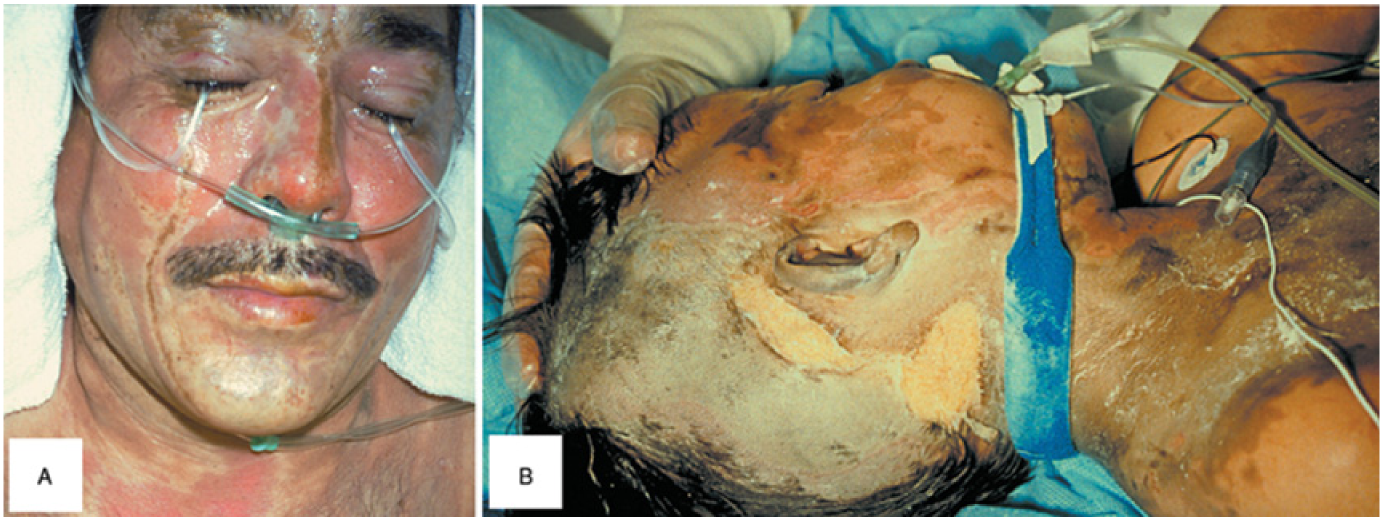


Figure 8.17 A,B Chemical burns. Muriatic acid burns to the face and eyes (A). Morgan lens eye irrigation is being performed. Large partial-thickness and deep burn of the face form 90% hydrosulfuric acid that spilled on a child (B).

Hydrofluoric acid requires special mention, as this chemical agent behaves in a unique manner. This compound is often found in rust removal products and other aggressive cleaners. The acid will cause a liquefactive necrosis itself, but the fluoride ion in this compound can cause significant local and systemic problems. The affected areas often demonstrate limited injury, though the patient will have significant pain. The fluoride ion will rapidly bind to calcium, resulting in bone pain in the affected areas but in large exposures can cause lethal hypocalcemia. The wounds are treated first with thorough irrigation and then with 2.5% calcium gluconate gel topically. This will limit the spread of the fluoride ion and help with pain. Patients should be monitored for severe signs of hypocalcemia, including prolonged QT interval, torsades de pointes, and ventricular fibrillation. Intravenous calcium gluconate may be required in patients with severe hypocalcemia as a result of this exposure.

Electrical Burns

Electrical burns are differentiated into low voltage (<1000 V) and high voltage (>1000 V). There are four mechanisms of injury: direct contact, electrical arc, flame, and flash burn. Current passing through the body from the point of entry to the grounding exit subjects the skin and underlying tissues to direct electrothermal injury. Electrical arc happens when current sparks between two objects of different electrical potentials that are not in physical contact with each other. These are high-voltage burns that may cause electrothermal injury as well as flame burns by igniting flammable items on the person such as clothing. Flash burns are usually partial thickness and result from heat generated by nearby current arcs that cause thermal injury but do not actually enter the body (Figure 8.18 A–C, Figure 8.18 A,B, Figure 8.20 A–C).

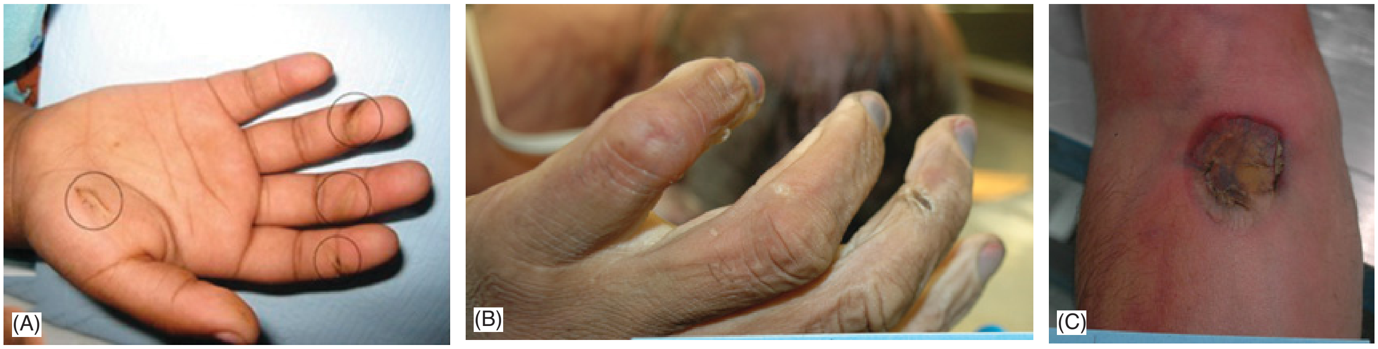


Figure 8.18 A–C Electrical burns. Low-voltage electrical burns to the hand from holding a defective electrical cord (A). Low voltage electrical burns of the fingers of the left hand (B). Low voltage burns of the right antecubital fossa (C).

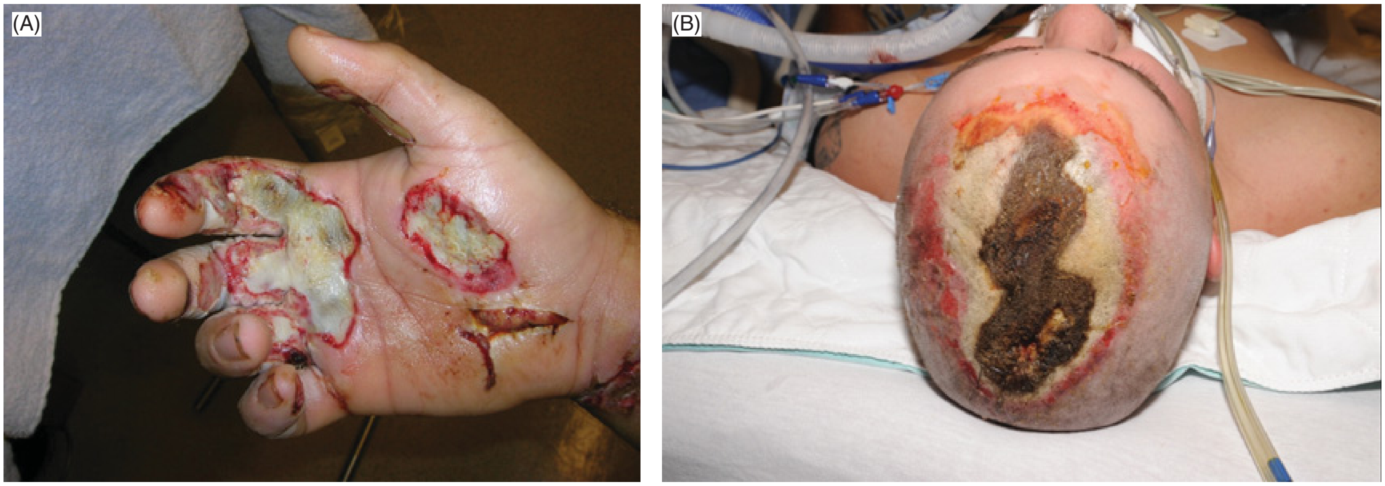


Figure 8.19 A,B Contact electrical burns of the hand (A). Contact electrical burns of the scalp (B).

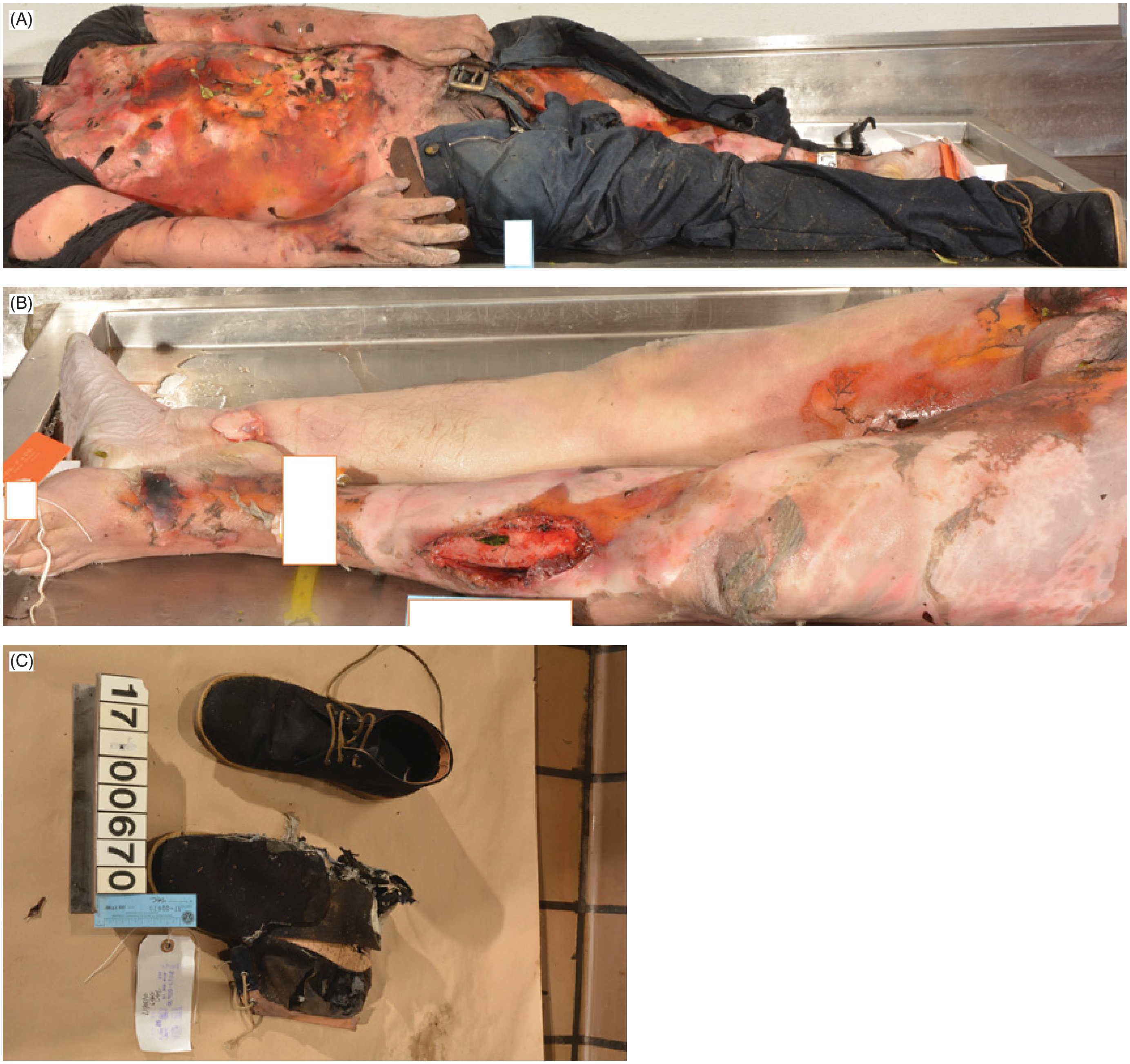


Figure 8.20 A–C Electrical burns. Fatal high-voltage burns travel from trunk down to the legs (A). Same patient with severe burns of the legs and exposed left tibia (B). Note the complete destruction of the left shoe (C).

Electrical burns are xtent of soft tissue damage. Electrical currents cause different amounts of tissue damage based on distinct tissue resistive properties. Nerves, vessels, and muscles are more susceptible to electrothermal damages, while bone and skin are less so. Extensive myonecrosis may develop with resultant myoglobin-induced renal failure. Treatment is based on aggressive fluid resuscitation to achieve a urine output of 1 ml/hr. Other commonly practiced treatments include the use of mannitol to induce an osmotic diuresis, and urine alkalinization with bicarbonate to prevent myoglobin precipitation in the renal tubules (Figure 8.21).

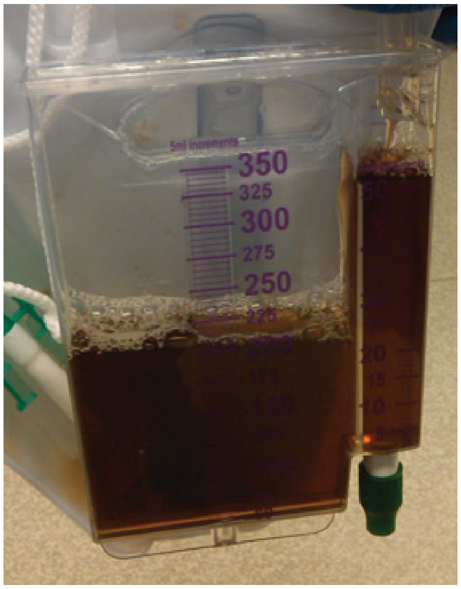


Figure 8.21 Dark-brown urine due to myoglobinuria in a victim with electrical-burn-induced rhabdomyolysis.

Patients should be monitored for a minimum of 6 hours, and often up to 24 hours, for cardiac arrhythmias and the development of extremity compartment syndrome. When suspected, decompressive fasciotomy should be promptly performed to minimize ischemic and pressure-induced myonecrosis. Nerves and the ophthalmic lens are particularly susceptible to electrical insult. Long-term sequelae include permanent debilitating peripheral neuropathy and cataracts.

Outcomes of Burn Injury

Advances in burn wound management and critical care have improved mortality over the last few decades. The highest mortality rate is still observed with concomitant inhalation injury. Otherwise, most of the mortalities occur at the ends of the age spectrum, usually due to multisystem organ failure.

Increased burn survival over the past several decades raises important quality of life issues. The most significant predictors of quality of life include the size of the full-thickness burn, age, degree of functional recovery of the hands, and perceived social support. Cosmetic outcomes range from minor skin discoloration or hypertrophic scars, to debilitating contractures. Over the long term, scars may require ongoing therapy, including laser resurfacing, contracture release, and intensive therapy to maintain functional mobility. These patients will need ongoing follow-up with burn or plastic surgeons to ensure that their function and cosmetic appearance of the burns are optimized. This is especially true in children, who will often require repeated releases of scars, especially during times of intense growth (Figure 8.22 A–C).

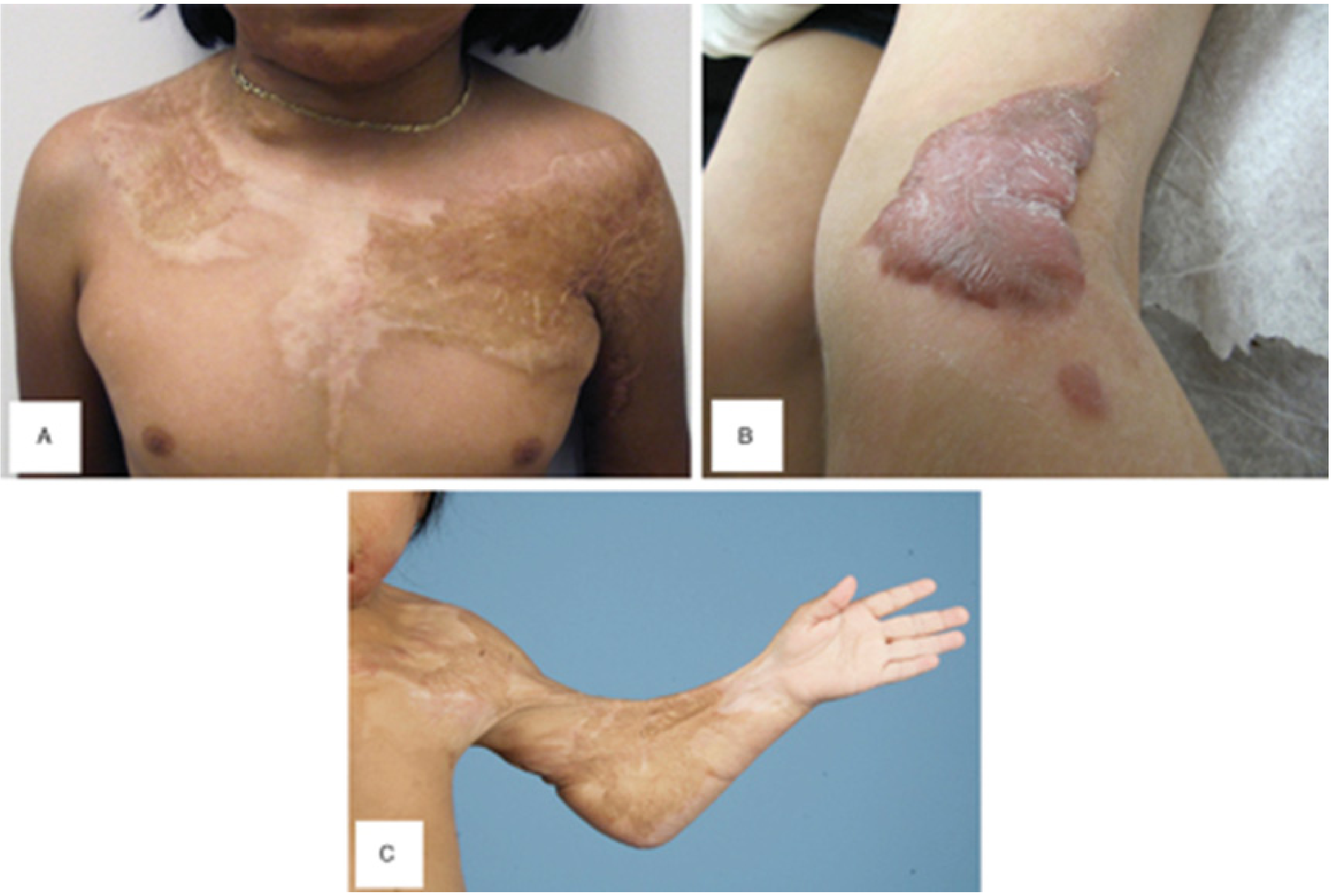


Figure 8.22 A–C Late complications from burn injury. Healed appearance of a split-thickness graft in a child who suffered a scald burn (A). There is noticeable skin discoloration in the area of the superficial partial-thickness burn that healed without surgery. Hypertrophic scarring from a small burn that healed over the lateral knee (B). Contractures in a child deep partial and full-thickness burns that were not surgically treated initially (C).

Chapter

9

Soft Tissue Injuries

Demetrios Demetriades, Elizabeth R. Benjamin, and Marko Bukur

Introduction

- Extensive blunt soft tissue trauma may occur after traffic accidents, falls from significant heights, and crush injuries. It is a common problem after major earthquakes or collapsed buildings (see Chapter 15, Disaster Medicine). Injuries can be closed, open, or both.
- Extensive soft tissue trauma following penetrating injuries may occur after high-velocity bullet wounds, closed-range shotgun injuries, and explosions (see Chapter 11, Ballistics).
- Severe soft tissue trauma is often associated with systemic complications, local tissue loss, infections, and limb loss.
- Meticulous systematic and local examination should be performed to rule out other associated injuries. Locally, the physician should evaluate for underlying vascular, nerve, tendon, and bone injuries, as well as compartment syndrome.
- Avulsion type injuries occur when a flap of tissue is separated from underlying tissue structures. The most extreme form of this injury is a degloving injury, which occurs when all the skin and subcutaneous tissues are separated from the underlying fascia. Tissue ischemia and necrosis of the flap segment are common and may lead to areas of large soft tissue defects.
- The Morel-Lavallée lesion is a closed, shear-force, degloving injury, which results in separation of the skin and subcutaneous tissue from the fascia over the underlying muscles. This space is filled with blood, lymph, or serosanguinous fluid. It is prone to infection and possible skin loss because of the disrupted blood supply and presence of devascularized tissue (Figure 9.1 A,B).

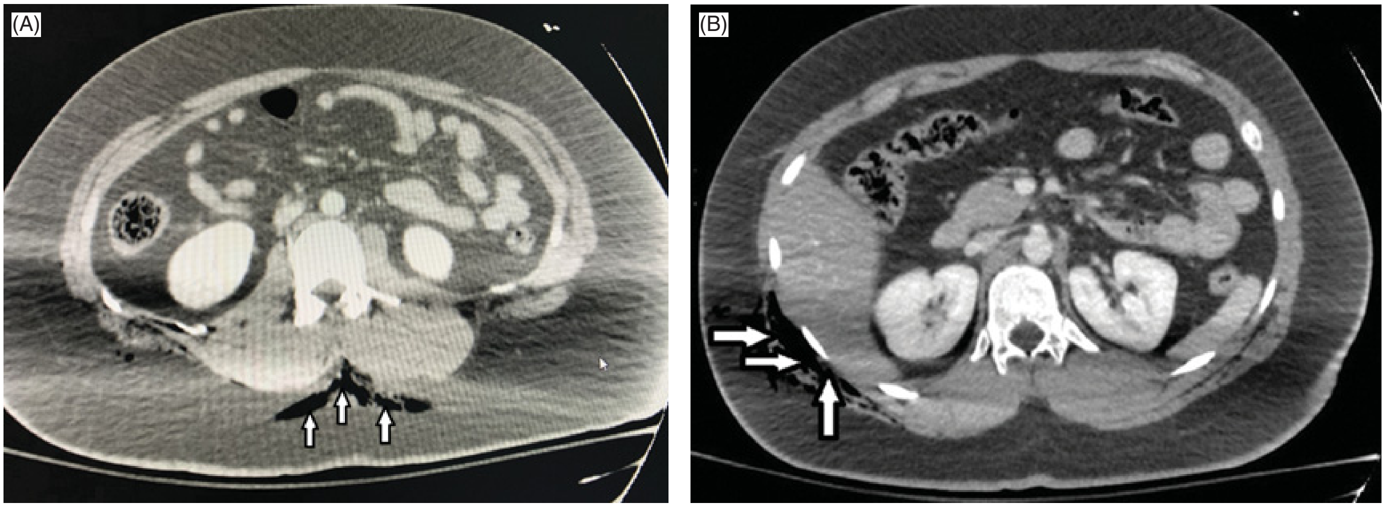


Figure 9.1 A,B Morel-Lavallée lesion of the back (A) and right flank (B).

- Mangled extremity injuries often involve soft tissue, neurovascular structures, and bones. These injuries require a multidisciplinary approach because of their complexity and high risk of serious complications, including amputation, renal failure, infection, and death (Figure 9.2, Figure 9.3).

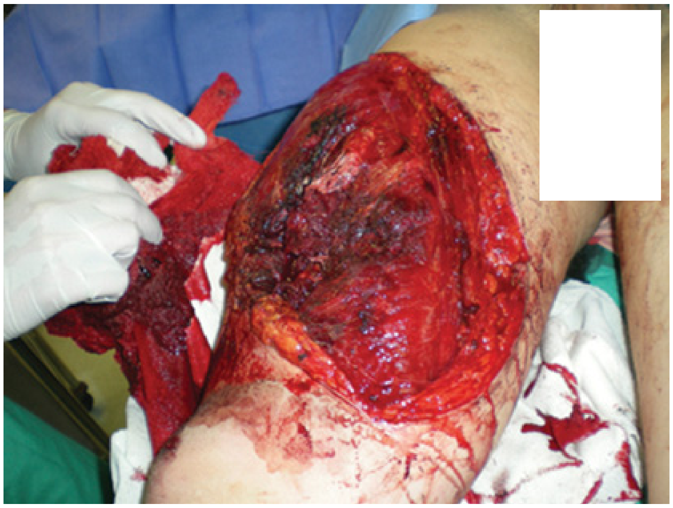


Figure 9.2 Auto-versus-pedestrian injury with significant tissue loss and an open femur fracture. The wound requires copious irrigation, intravenous antibiotics, and early coverage to reduce the risk of complications such as osteomyelitis.

Complications

Systemic complications may occur after extensive soft tissue trauma:

1. Hypovolemic shock due to blood loss externally or into the tissues.
2. Renal failure due to rhabdomyolysis and myoglobinuria.
3. Electrolytic abnormalities, including hyperkalemia, hypocalcemia, and hyperphosphatemia. This specific combination of electrolytic abnormalities is highly cardiotoxic.
4. Hematological changes, including disseminated intravascular coagulopathy due to release of tissue thromboplastin from the injured tissues.

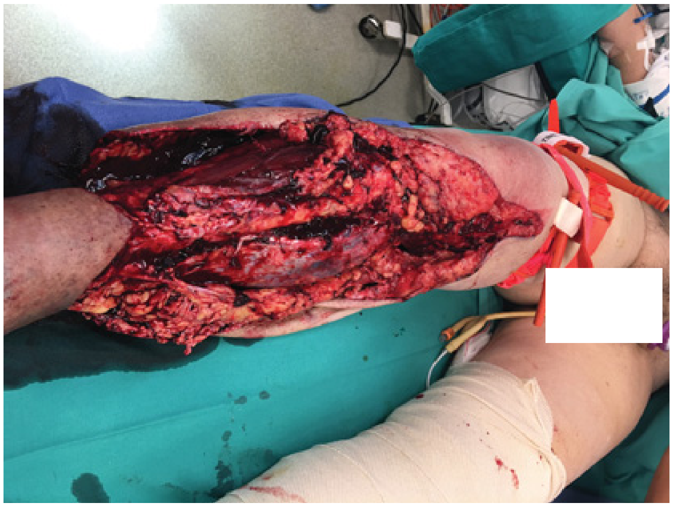


Figure 9.3 Mangled extremity following a motorcycle collision. There is extensive soft tissue loss, vascular trauma, and fracture. The management of this injury is benefitted by a multidisciplinary team approach.

Local Complications

1. Compartment syndrome.
2. Infection of open wounds, hematomas, or devitalized tissue. In severe cases, this may progress to necrotizing soft tissue infection.

Investigations and Monitoring

All patients with extensive soft tissue trauma should have serial monitoring of hemoglobin levels, platelet count, coagulation parameters, electrolytes, creatinine phosphokinase (CPK) levels, and recording of hourly urine output, as well as close monitoring for compartment syndrome (Figure 9.4 A,B). Vascular studies (CT angiography, vascular ultrasound, or formal angiography) should be performed as indicated to evaluate for associated vascular injuries.

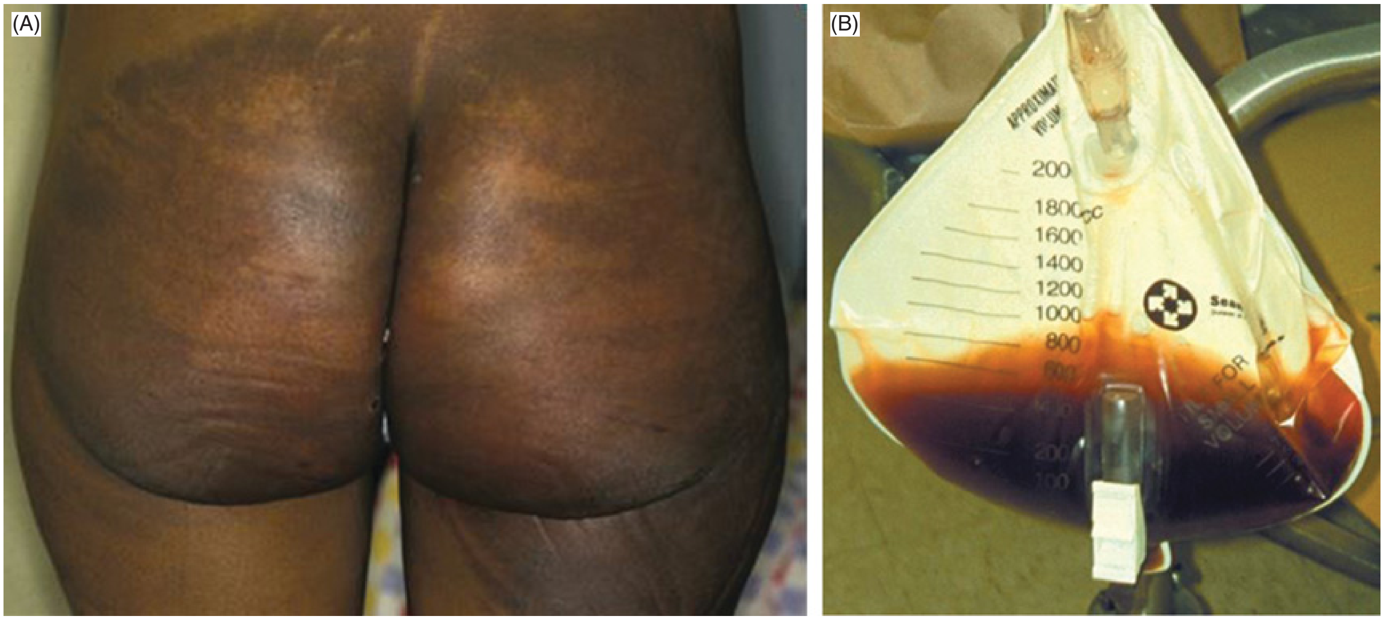


Figure 9.4 A,B Violent beating on the buttocks and posterior thighs (A). These injuries place the patient at high risk of compartment syndrome, rhabdomyolysis, and renal failure. Note the brownish color of the urine due to myoglobinuria (B).

Management

The initial management should follow ATLS guidelines. The treatment should address local and systemic problems. The local care of large open wounds should be provided in the operating room, usually under general anesthesia. Only minor wounds should be managed in the emergency room. Antibiotic and tetanus prophylaxis should be administered routinely.

Initial local priorities should include hemorrhage control and a neurological exam. Hemorrhage control is best achieved with direct compression or application of a tourniquet. Blind clamping of bleeding vessels in the emergency department is not advised as this can lead to further neurovascular injury. Foley catheter balloon tamponade should be considered in deep bleeding wounds if direct compression is not effective and a tourniquet cannot be applied, such as in junctional injuries, or bleeding wounds in the buttock or neck (see Chapter 3, Neck Injury) (Figure 9.5, Figure 9.6, Figure 9.7 A–C).

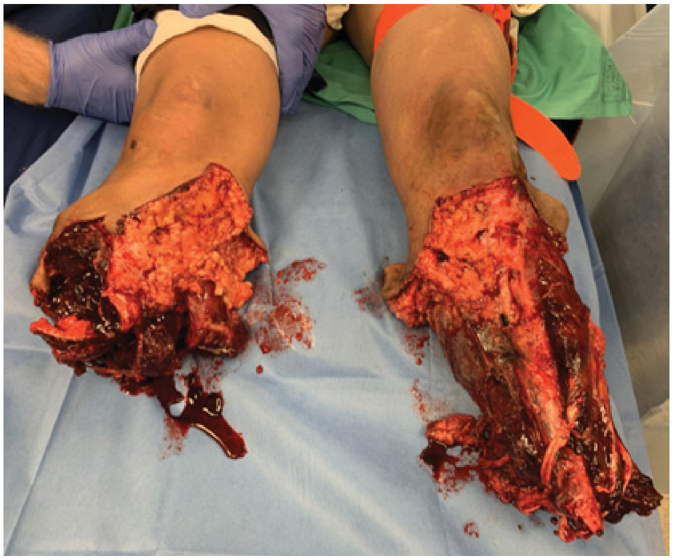


Figure 9.5 Victim struck by a train, resulting in on-scene amputation. Control of life-threatening bleeding with tourniquet application should be the most immediate priority.

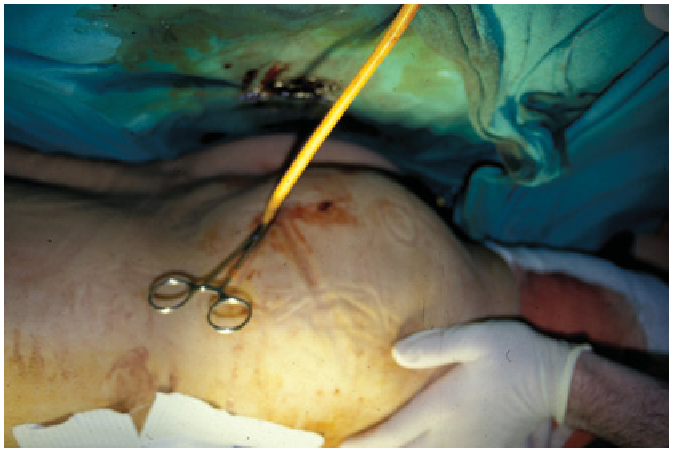


Figure 9.6 Foley catheter balloon tamponade of severe bleeding from a penetrating injury to the buttock. The catheter is inserted in the wound tract and the balloon inflated in various parts of the tract until the bleeding is controlled. A clamp is applied on the catheter to prevent bleeding through the lumen.

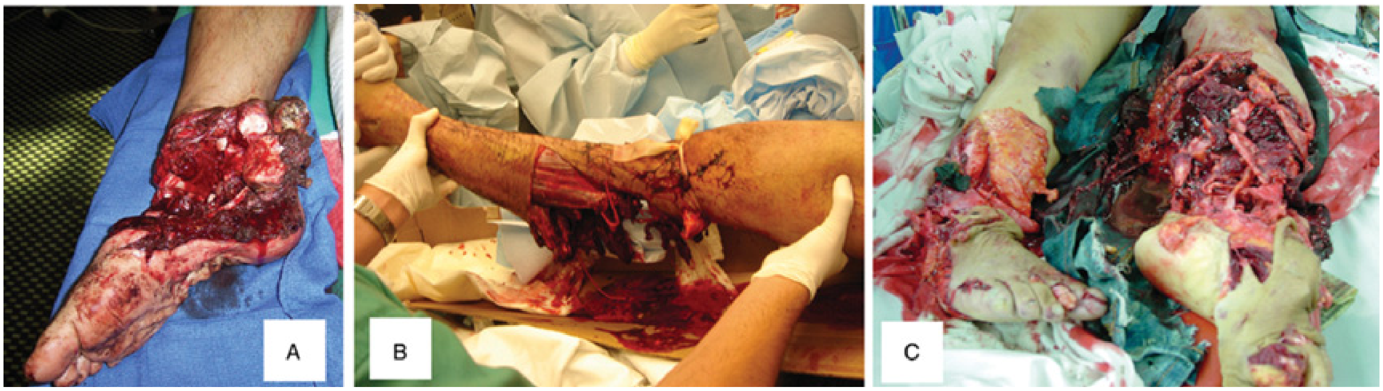


Figure 9.7 A–C Mangled extremities. Bleeding control by direct pressure or tourniquet application is the first priority. Many of these cases require amputations. Attempts to salvage severely mangled limbs require a multidisciplinary team, multiple operations, and may result in serious complications and prolonged hospitalization, with ultimately low success rates.

Documentation of neurologic function and extent of tissue damage is important in cases where the extremity is unsalvageable and primary amputation necessary. The options of primary amputation, reimplantation, or limb salvage should be a multidisciplinary decision, taking into account the extent of the injury, other associated injuries, the clinical condition of the patient, hospital resources, and triage issues in mass disasters.

Primary repair of soft tissue wounds should be considered only in selected cases with clean incising wounds. In the majority of cases of extensive soft tissue trauma, the wound should be debrided and left open for delayed closure. In dirty wounds or in the presence of devitalized tissue, repeat surgical debridements in the operating room may be necessary. Negative pressure therapy, with or without an automated irrigation system, is helpful in removing any infected exudate and reducing wound volume (Figure 9.8 A,B). Negative pressure therapy is contraindicated in the setting of incomplete hemostasis because it may worsen bleeding.

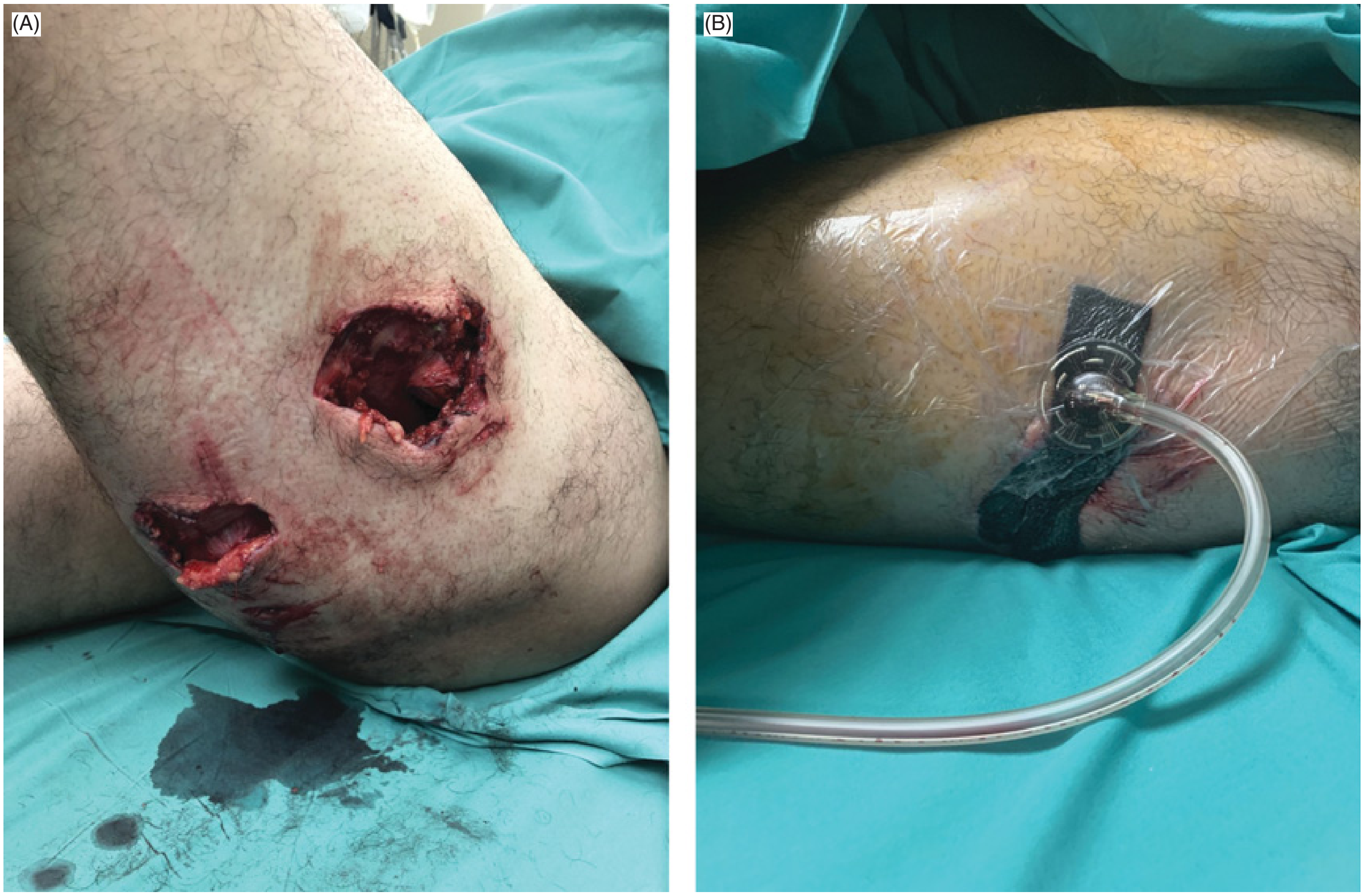


Figure 9.8 A,B Extensive soft tissue trauma following impalement. The wounds were managed with negative pressure therapy and delayed closure due to the high risk of infection with primary closure.

In extensive soft tissue trauma, the risk of acute kidney injury can be reduced by early and aggressive fluid resuscitation, urine alkalinization with intravenous bicarbonate to maintain a slightly alkaline urine pH, and diuresis to maintain urine output >1 ml/kg/hour. Mannitol administration should be considered in hemodynamically stable patients with very high CPK levels.

In extremity or buttock soft tissue injuries, the muscle compartments should be monitored clinically, with serial CPK monitoring and compartment pressure measurements. In cases with a compartment syndrome, timely decompressive fasciotomies should be performed to avoid serious systemic or local complications (see Chapter 10, Extremity Compartment Syndrome).

Dog Bite Injuries

Dog bites are the most common mammalian bite injuries. Most commonly, they involve the extremities, followed by the head and neck, and trunk. Children are more likely to suffer injuries to the head and neck due to their smaller stature. Injuries in this body area can cause scalp avulsions, intracranial bleeding, or major vascular injury in the neck.

Dog bites may cause a variety of soft tissue injuries, including punctures, avulsions, lacerations, and severe crush injury. Additionally, there is a significant incidence of vascular, nerve, and tendon injuries, especially from larger dog breeds or law enforcement animals. Careful neurovascular and tendon examination, and in the appropriate cases, CT angiography should be performed. For large wounds, X-rays are important to evaluate for retained foreign bodies and underlying fractures. (Figure 9.9 A,B, Figure 9.10 A,B).

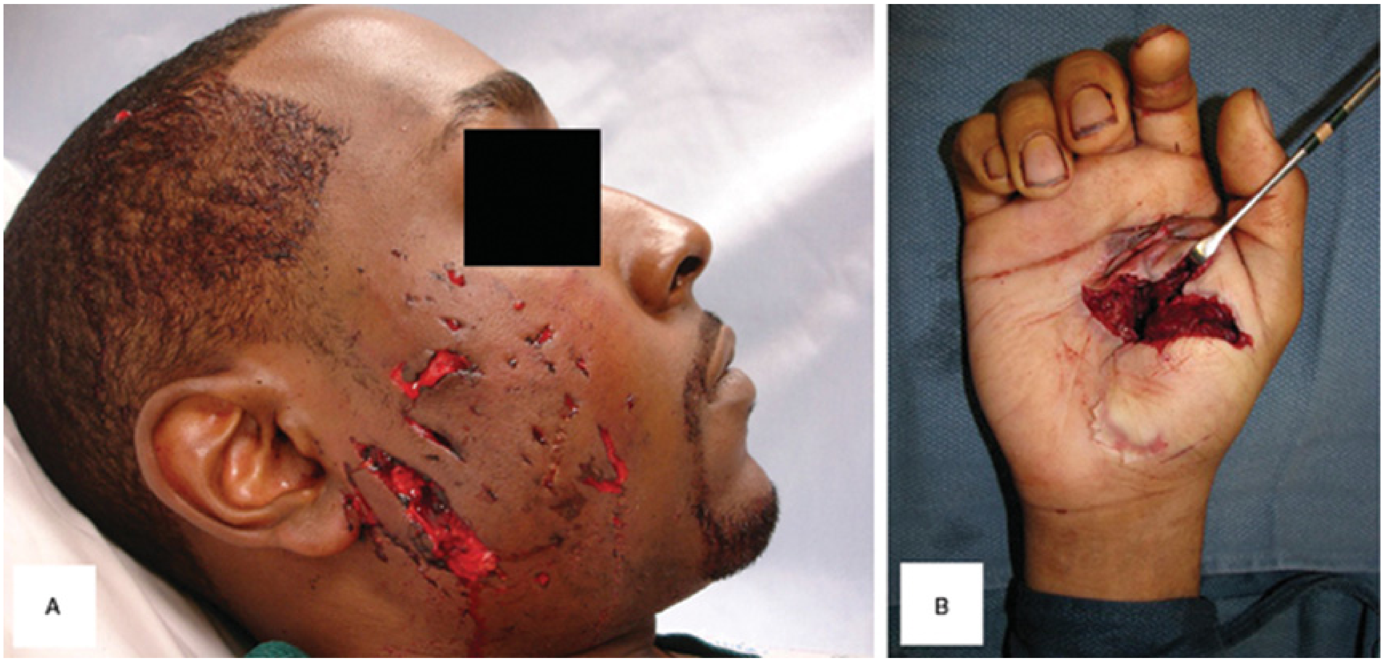


Figure 9.9 A,B Multiple facial lacerations and puncture wounds caused by a pit bull bite attack, resulting in a parotid gland injury. The puncture wounds should be cleaned and left open. However, incising wounds like the one over the parotid should be repaired primarily (A). Laceration of the hand with partial degloving of tissue from a pit bull bite. Hand injuries should be evaluated clinically for underlying tendon injuries and radiologically for associated fractures (B).

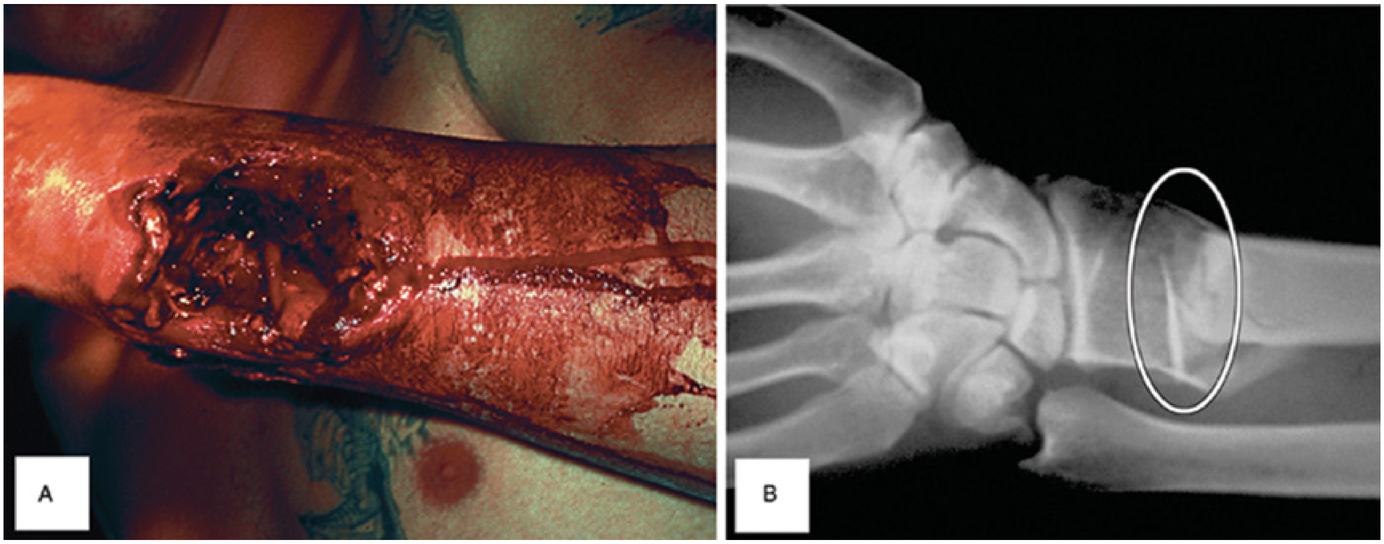


Figure 9.10 A,B Severe dog bites to the forearm with tissue loss (A) and underlying radial fracture (B). The tendons and nerves should be evaluated clinically.

The hand contains numerous bones, nerves, tendons, and joints enclosed within a small space and in a relatively superficial location. Infection in the hand is common because of the relatively avascular structures (fascia, tendons, joints). For the same reason, infection of the hand can rapidly progress, resulting in finger loss or permanent disability if not rapidly treated. For these reasons, an early orthopedic consultation should be obtained when the bite involves the hand (Figure 9.11 A,B).

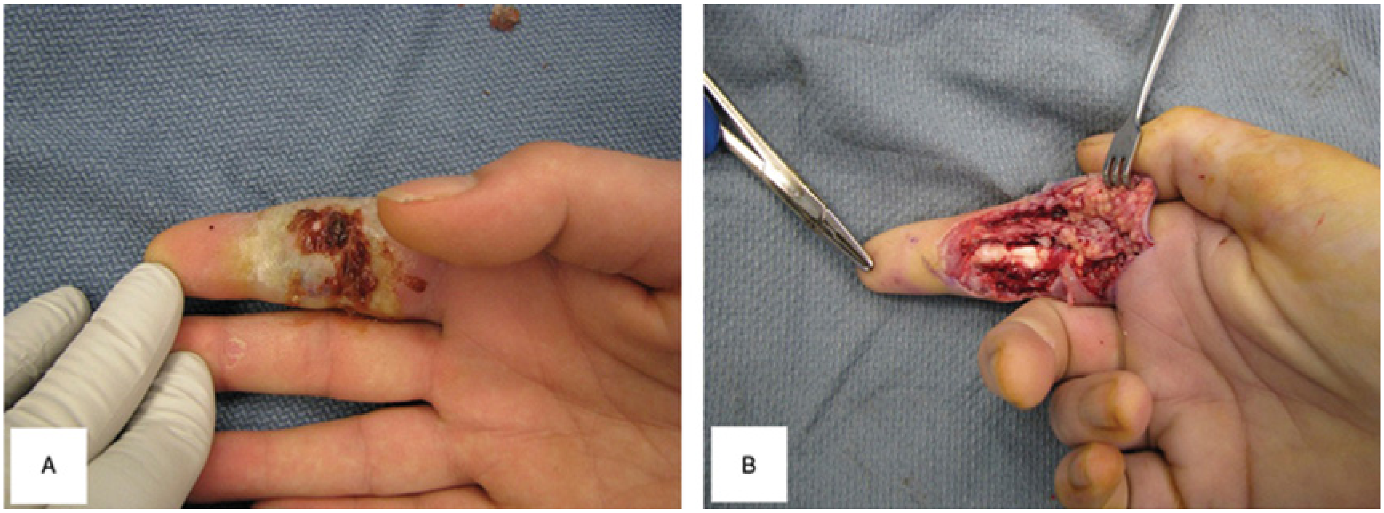


Figure 9.11 A,B Dog bite injury with delayed presentation and severe finger infection (A). Surgical exploration shows spread of the infection along the tendon sheath (B).

Primary closure of dog bites should only be considered in lacerations after extensive irrigation and debridement of devitalized tissues. This is particularly important for face and neck bites, where cosmesis is a concern and wound infection less likely due to rich vascular supply. Puncture wounds, any wounds presenting late after injury, or those with signs of infection should not be closed. Tetanus history should also be obtained from the patient and boosters and/or immunoglobulin administered where appropriate.

Risk factors for wound infection after dog bite injury include the anatomic site (e.g., hands are at high risk), type of bite (puncture vs. laceration vs. crushing), delay in treatment, and comorbid factors (e.g., diabetes, vascular disease, immunosuppression). Infections are often polymicrobial. Pasteurella species are commonly isolated organisms. Other common isolates include Streptococcus, Staphylococcus, Neisseria species, Morexella, Fusobacterium, and Bacteroides.

Pasteurella is sensitive to penicillin, tetracycline, and cephalosporins but resistant to erythromycin and aminoglycosides. A single dose of antibiotic prophylaxis should be considered after simple dog bite injuries. Longer antibiotic prophylaxis, for three to five days, should be considered in complex wounds or in those with risk factors, as described previously. Amoxicillin–clavulanic acid is a good single-agent choice for prophylaxis in patients that are not allergic to penicillin. Alternative choices include doxycycline with metronidazole, fluoroquinolones with clindamycin, or trimethoprim-sulfamethoxazole. Outpatient oral antibiotic treatment for a 3–5 day period is acceptable in those patients without clinical signs of local or systemic infection.

Established infections should be treated with intravenous antibiotics in the inpatient setting, as these wounds are likely to require surgical debridement. Initial empiric therapy should cover the canine oral flora and potential skin flora of the patient. Acceptable choices for initial therapy include β-lactam/ β-lactamase inhibitor combinations (e.g., piperacillin-tazobactam, ampicillin-sulbactam), carbapenems, or cephalosporins and fluoroquinolones with metronidazole. Urgent surgical evaluation should also be obtained for source control particularly for injuries to the hand because of the high risk of permanent disability or finger loss. Serial surgical debridement may be necessary. Negative

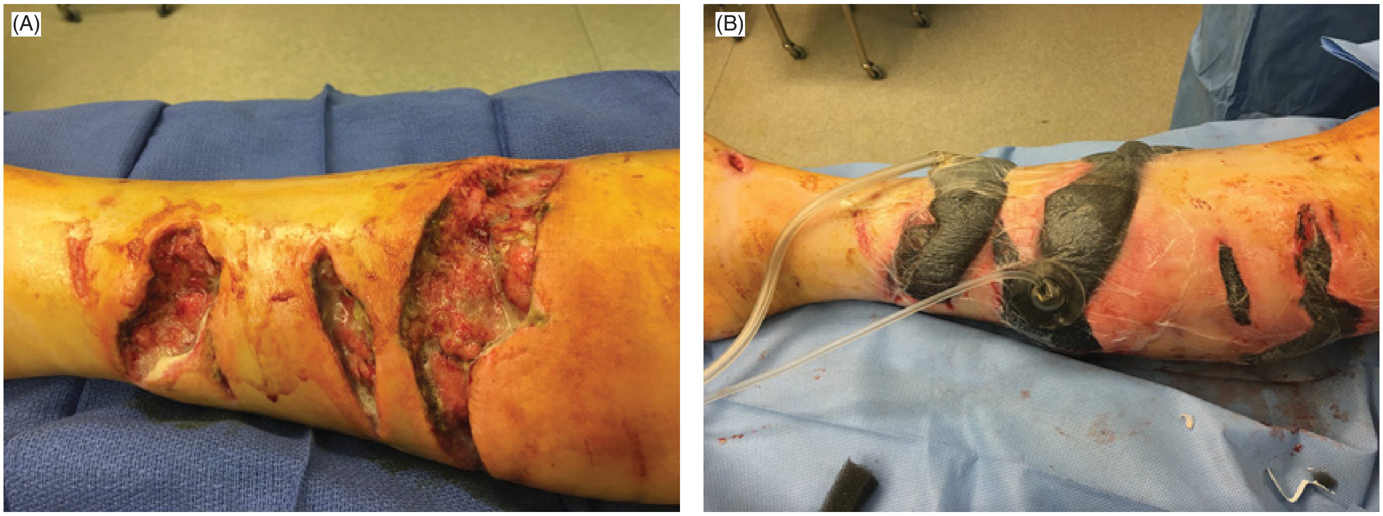


Figure 9.12 A,B Infected dog bites of the forearm treated with a combination of negative pressure and irrigation system.

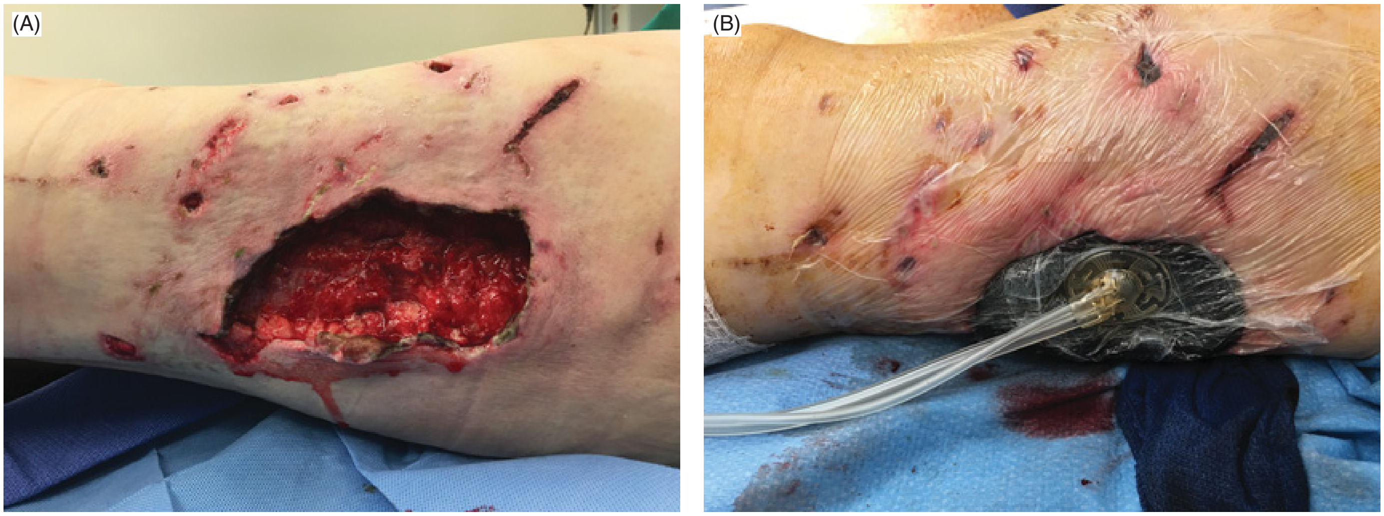


Figure 9.13 A,B Infected dog bites with cellulitis of the forearm treated with a combination of negative pressure and irrigation system and intravenous antibiotics.

pressure therapy with or without an irrigation system may be a useful adjunct in the management of infected wounds after debridement that cannot be closed (Figure 9.12 A,B, Figure 9.13 A,B).

Infection with rabies is the most serious complication associated with canine bites and is associated with a very high mortality. Aggressive screening and prophylaxis in the appropriate cases should be followed. When the offending animal is unavailable for observation, has unknown vaccination status, or is suspected to be a stray, the local public health office should be consulted to obtain the local prevalence of rabies. Rabies prophylaxis should be given based upon the exposure risk.

Cat Bite Injury

Cat bites are the second most common mammalian injury after dog bites. Many of these injuries are not initially evaluated by medical personnel because of their innocuous appearance, thus delaying presentation. However, the sharp, slender teeth of cats cause puncture wounds that inoculate organisms deep into the soft tissues, increasing the risk of infection. If the bites involve the hand, there is a risk of osteomyelitis or septic arthritis.

Prophylactic antibiotics and close follow-up are necessary to detect any infection at an early stage. The oral flora of cats is almost identical to that in dogs, and thus antibiotic prophylaxis or treatment is similar. Rabies transmission, though less common than in dogs, is possible and should be screened for adequately. Tetanus history should be obtained from the patient, and prophylaxis should be administered where appropriate.

Cat bites are almost always punctures and should never be sutured because of the high risk of infection (Figure 9.14 A,B).

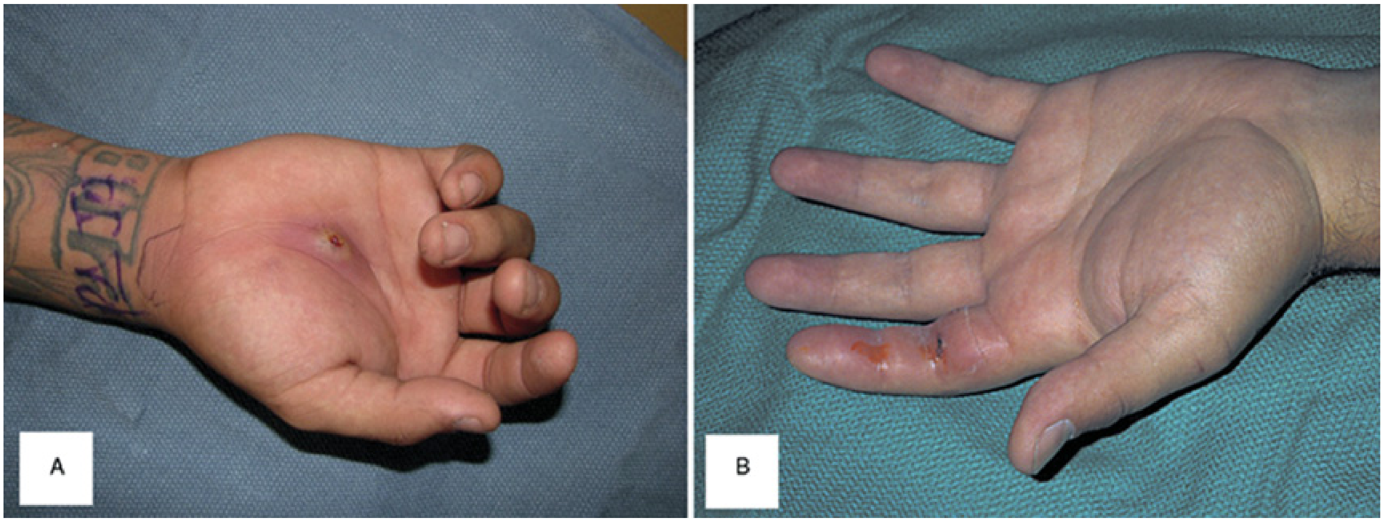


Figure 9.14 A,B Examples of typical cat bite injuries. Note the small puncture wound of the palm surrounded by erythema and edema from resultant infection (A). Infected cat bite resulting in flexor tenosynovitis of the index finger (B).

Human Bite Injury

Most commonly, these bites are the result of assault with injuries frequently involving the hands. The crushing and tearing mechanism in human bites causes tissue destruction and devitalization. Additionally, the human mouth contains a high concentration of about 100 different virulent bacteria. This combination results in a high incidence of infections. The most common pathogens are Streptococcus and Staphylococcus species.

A special category of human bites is the clenched-fist injury, otherwise known as "fight bites." These injuries occur from one individual punching another in the mouth with considerable force at impact. The wounds classically appear over the dorsal aspect of the third, fourth, or fifth metacarpophalangeal joints, and are benign-appearing due to their small size. Careful examination of the dorsum of the hand in the "clenched-fist" position should be carried out after a history of fist fighting. In more than 50% of clenched fist injuries, there is penetration of the metacarpophalangeal joint and often tendon and cartilage injury. The bone may be involved in many cases. Patients typically extend their hands after injury, which allows deeper penetration of bacteria into the joint space or tendon sheath, allowing proximal extension into the hand or wrist and causing tenosynovitis, septic arthritis, or osteomyelitis. Infections may spread aggressively, due to the complex tendon sheath anatomy of the hand as well as the relative avascularity of these structures. Plain X-ray investigation should also be done to rule out occult fractures. All clenched-fist injuries should be examined by a hand surgeon due to the limited reconstruction options if an infection develops. Only 10% of patients with septic arthritis will regain function, and amputation may be necessary in many cases (Figure 9.15).

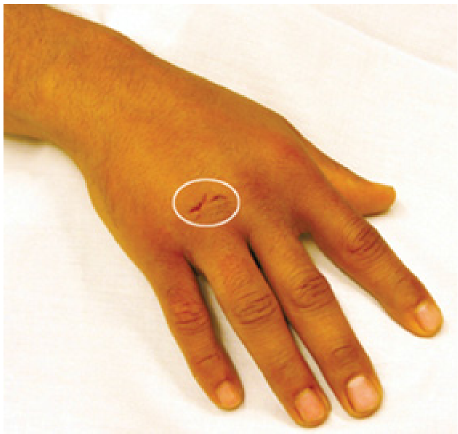


Figure 9.15 Classic appearance of the "fight bite" injury. It is important to rule out underlying tendon or bone injuries, or joint penetration. This type of injury is associated with a high risk of infection.

Most human bites can safely be managed on an outpatient basis. However, infected bites and those with joint or tendon sheath penetration should be admitted for intravenous antibiotics, debridement, and close observation.

The early management of human bites should include wound irrigation to facilitate examination and removal of any visible foreign bodies. Immobilization at a functional position and elevation of the involved part are essential. Surgical exploration may be indicated for those bites where tendon or joint damage is suspected.

Most bites with laceration or loss of tissue, especially on the face, can be primarily closed. However, puncture bites, any type of bites on the hands, or cases with delayed presentation to the emergency room should never be sutured because of the high risk of infection. In cases with primary repair, close follow-up should be done in the first 48–72 hours after wound closure, to ensure that no infection has occurred (Figure 9.16 A,B). In

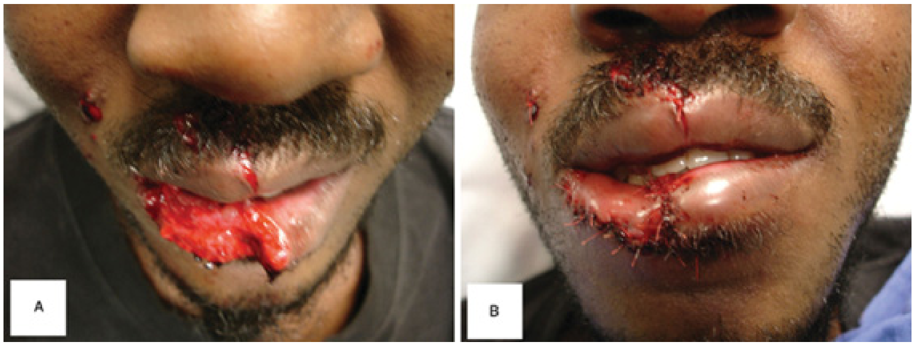


Figure 9.16 A,B Human bite of the lower lip with loss of tissue (A). Primary repair is safe and provides good results (B).

addition, prophylactic antibiotics and tetanus therapy are necessary in these high-risk wounds. Acceptable agents for prophylaxis include amoxicillin-clavulanic acid, fluoroquinolones with clindamycin or trimethoprim-sulfamethoxazole, or doxycycline in those that are allergic to penicillin. Prophylaxis is generally administered for a period of three to five days. Established infections, such as cellulitis, abscess formation, and septic arthritis, will require longer duration of therapy, and treatment should be tailored based upon available cultures (Figure 9.17 A,B, Figure 9.18 A,B).

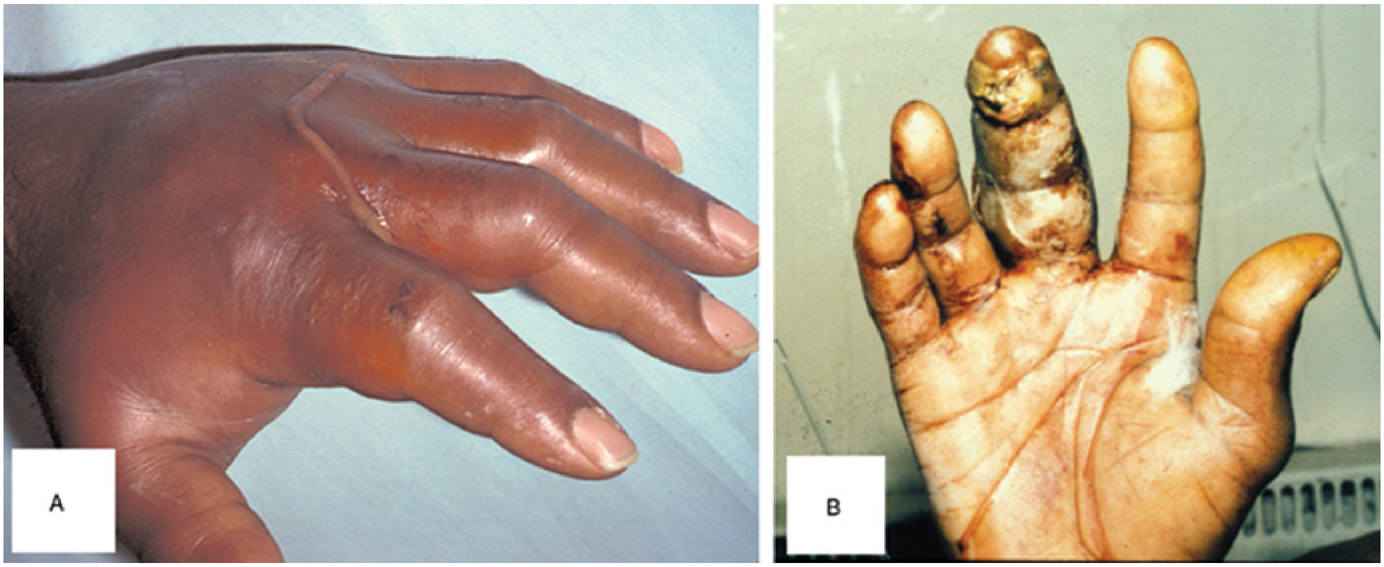


Figure 9.17 A,B Severe infection of the hand after a clenched-fist injury (A). Severe tenosynovitis and osteomyelitis of the middle finger following a human bite (B). In neglected cases like this, there is a high risk for finger loss.

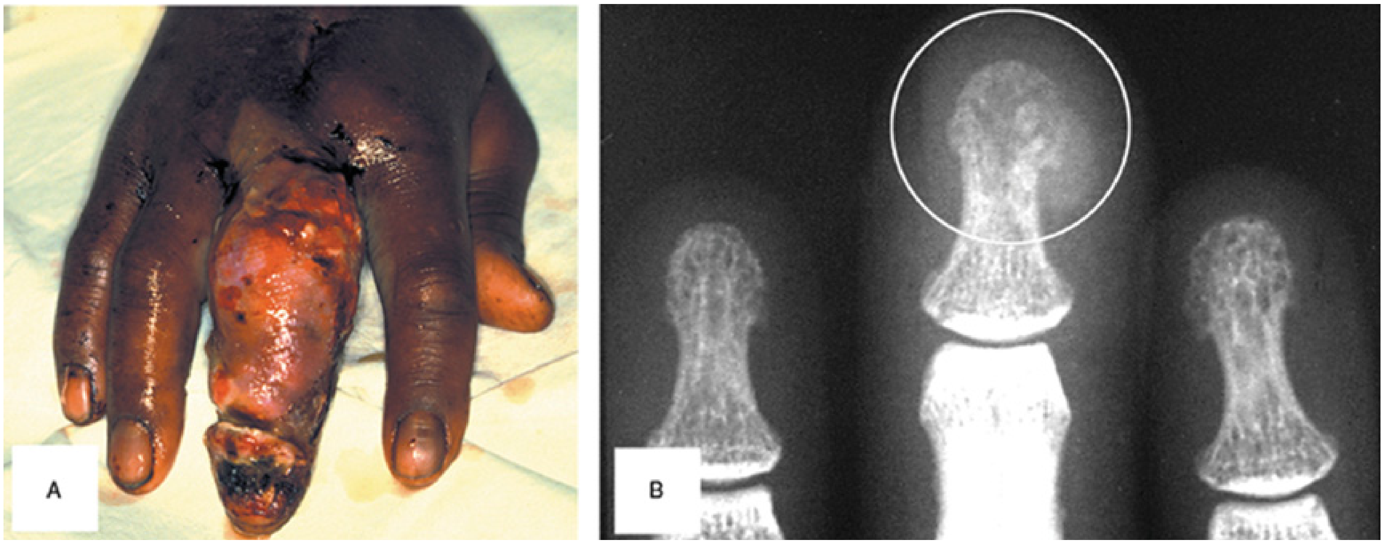


Figure 9.18 A,B Severe tenosynovitis and osteomyelitis of the middle finger following a human bite (A). Note osteomyelitis of the distal phalanx (B).

It is also important to consider infectious disease transmission after human bite exposure. Transmission of herpes, syphilis, hepatitis B and C, HIV, as well as other infectious pathogens has been reported.

Wild Animal Attacks in Urban Areas

Carnivore attacks in urban areas are rare but do occur. They include mountain lion and other large cat and bear attacks. Large cats tend to attack the head and neck area of their victims. Bears often stand and attack the victim's head, face, and neck using their claws, resulting in large lacerations or tissue avulsion (Figure 9.19 A,B). Bites result in large areas of tissue loss, often requiring complex reconstruction.

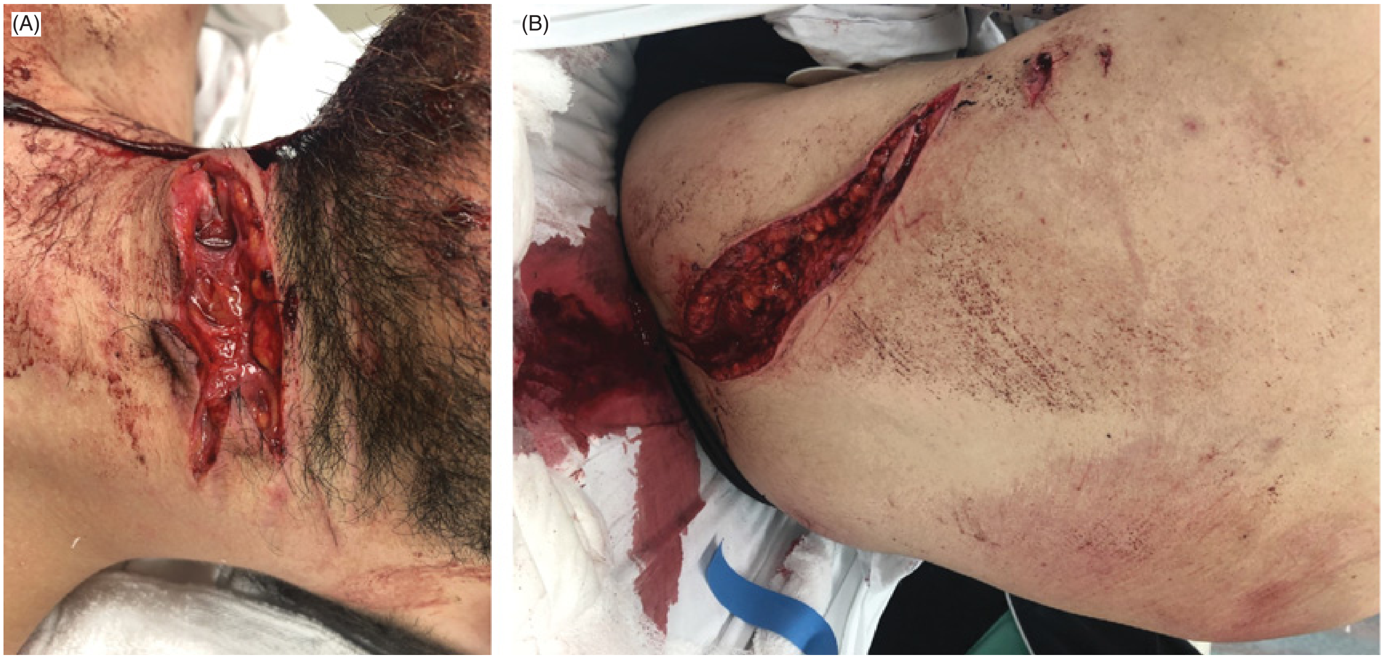


Figure 9.19 A,B Bear attack with a large laceration in the neck and a tracheal injury (A). The same patient with a large wound on the posterior shoulder (B).

High-Pressure Injection Injury

High-pressure injection injuries to the hand are often occupationally related and have devastating complications. These injuries are commonly the result of paint guns, grease guns, and diesel injectors. Though paint and grease are the most commonly injected chemicals, other substances may be implicated. These injuries involve tremendous forces, as the injector guns use pressures of 2,000–10,000 psi.

Physical examination may initially reveal an innocuous-looking wound. As time progresses, a severe inflammatory process may develop. The affected area is swollen and may be pale from associated vascular compromise. Radiographs may reveal discrete opaque areas that can help delineate the extent of deep injury. Emergency therapy includes splinting, tetanus prophylaxis, and broad-spectrum antimicrobial coverage. These injection injuries are extremely serious and have a high rate of amputation and long-term disability. Urgent hand surgery consultation is imperative, as most patients will require emergency operative debridement and decompression (Figure 9.20 A,B).

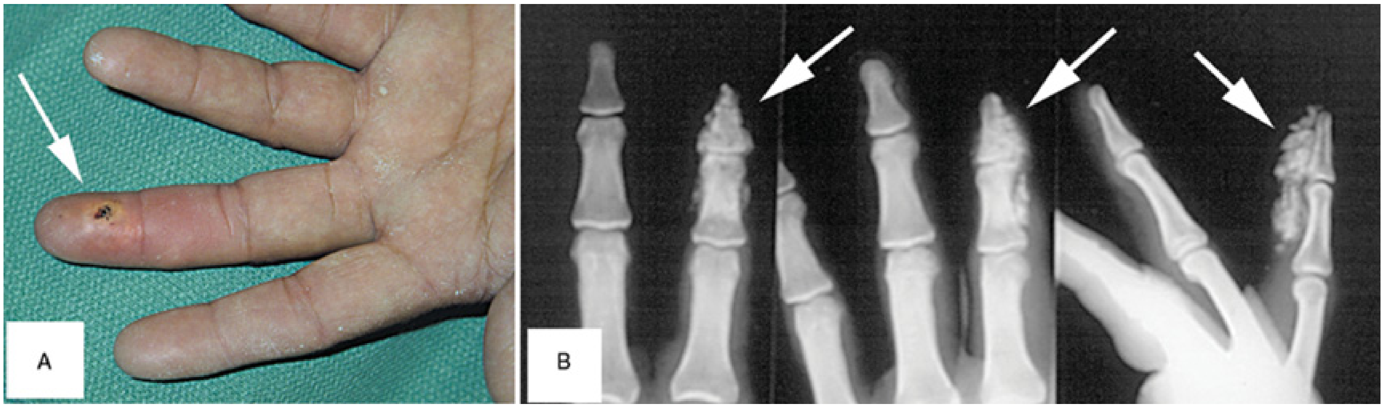


Figure 9.20 A,B High-pressure injection injury. Despite their innocent-looking appearance, they are serious injuries (A). Radiological appearance of paint injected under pressure along the flexor tendon sheath (B).

Retained Foreign Body

Retained foreign bodies in an open wound commonly result in infection and failure to heal. In suspicious mechanisms of injury, all open wounds should be carefully examined to rule out the presence of a retained foreign body. Plain radiographs are reliable in detecting radiopaque objects, but commonly missed materials include wood or plastic. Certain types of glass that contain lead are radiopaque, but nonleaded glass is not visible on plain X-rays. In these cases, other imaging modalities, such as ultrasound, CT scan, or MRI, may be necessary.

Bullets or missile fragments are a special category of retained foreign body. Routine removal of these missiles does not reduce the risk of infection, and in most cases, they can be left in the body. Removal should be considered in superficially located missiles and in cases with intra-articular location or compression of major nerves or the spinal cord (Figure 9.21 A,B).

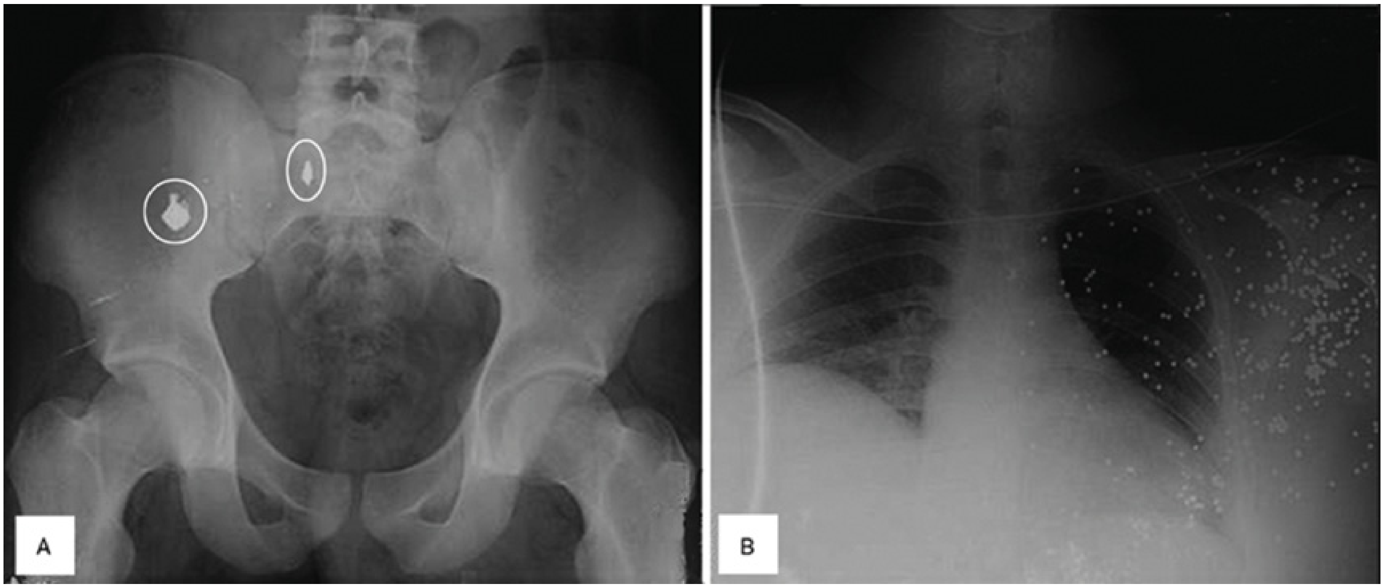


Figure 9.21A,B Retained bullets (A) or pellets (B) do not require routine removal. Removal should be considered in superficially located missiles and in cases with intra-articular location or compression of major nerves or the spinal cord.

Intentionally inserted sharp foreign bodies into the soft tissues, usually needles, may be found in psychiatric patients and victims of child or elderly abuse. Routine removal of these objects in asymptomatic psychiatric cases may not be advisable because most patients usually return with another self-inserted foreign object. In cases of abuse, the foreign bodies should be managed case by case, based on the location of the object and the complexity of any operation to remove them (Figure 9.22).

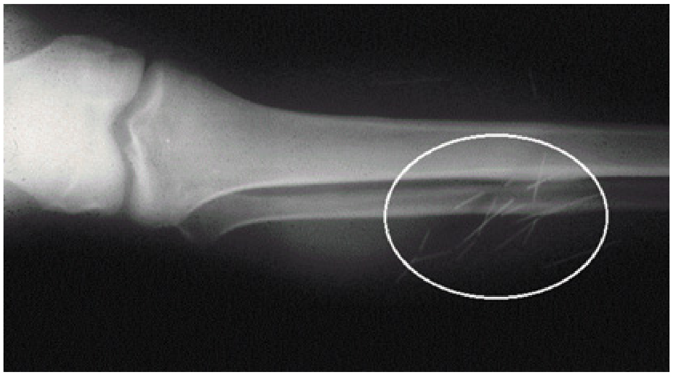


Figure 9.22 Multiple needles inserted in the subcutaneous tissue by a psychiatric patient.

Impaled foreign objects found superficially in the soft tissues and with no evidence of vascular injury, can be removed in the emergency room. However, deeply embedded objects should not be removed in the emergency room. The objects should be stabilized during transportation to prevent further damage and in the appropriate cases a CT angiogram should be performed to evaluate for vascular injury. Objects should be removed in the operating room, and after debridement of dead tissue, wounds should be left open and covered with a regular dressing or a negative pressure therapy system (Figure 9.23).

Tips and Pitfalls

- Large lacerations or avulsions due to animal bites seen soon after the injury can safely be cleaned and sutured. Puncture

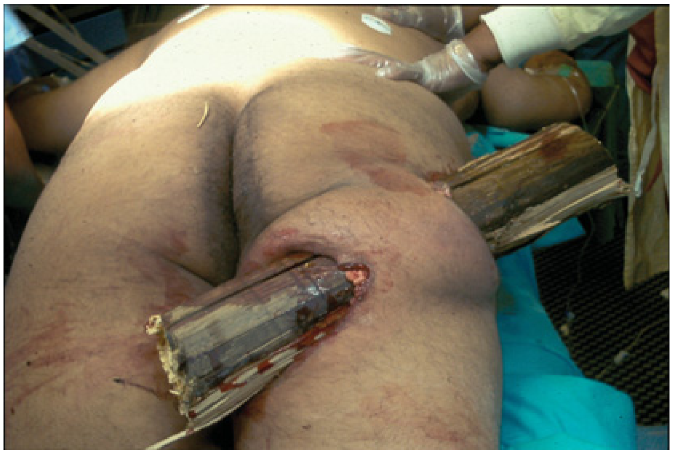


Figure 9.23 Impaled large piece of wood fence in the posterior upper thigh. The foreign object should be removed in the operating room, and the wound should be debrided and not sutured.

wounds should never be sutured because of the high risk of infection.

- Human bites resulting in lacerations or tissue loss, especially on the face and neck, can safely be repaired.
- Human or animal bites of the hand are associated with a high incidence of infection. Revaluate within 24–48 hours for any signs of infection.
- Cat bite wounds may look superficial, but they are associated with a high incidence of infection.
- Human or animal bites on the hand should be evaluated for joint violation, which is associated with a high risk of infection and functional disability.
- Infected hand bite injuries should be admitted for intravenous antibiotics and surgical debridement.

Chapter

10

Extremity Compartment Syndrome

Elizabeth R. Benjamin and Demetrios Demetriades

General Principles

The extremity compartment syndrome is an acute, limb, and potentially life-threatening emergency that occurs when the pressure in a muscle compartment increases to levels that cause reduced tissue perfusion resulting in ischemic damage to the muscles and nerves.

The normal muscle compartment pressure is less than 8 mmHg. Increase of the muscle compartment pressure >30–40 mmHg is generally considered a surgical emergency and an indication for fasciotomy. An alternative to the absolute compartment pressure is the compartment perfusion pressure (CPP):

CPP = Diastolic pressure – Compartment pressure

A CPP <30 mmHg often indicates severe soft tissue ischemia and is an indication for an emergency fasciotomy.

Conditions that might cause extremity compartment syndrome include severe fractures, crush injury, ischemia due to vascular injury, venous outflow obstruction, circumferential burns, snake or spider bites, excessive exercise, and constricting bandages or casts. This complication is sometimes observed in unconscious or obtunded patients due to drug or alcohol intoxication and prolonged limb compression. Secondary compartment syndrome may occur in trauma or burn patients receiving massive fluid resuscitation (Figure 10.1, Figure 10.2, Figure 10.3, Figure 10.4).

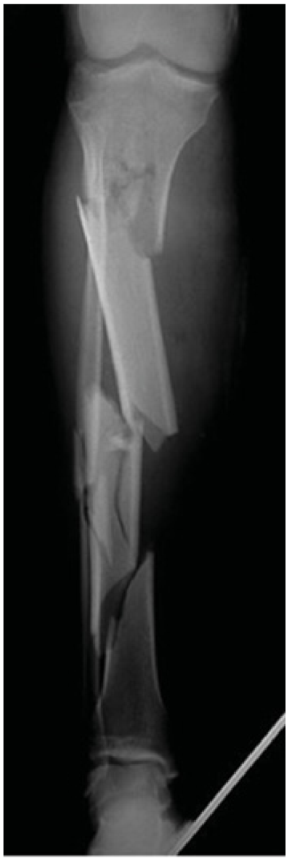


Figure 10.1 Severe communited fractures are a high risk for compartment syndrome and should be monitored closely.

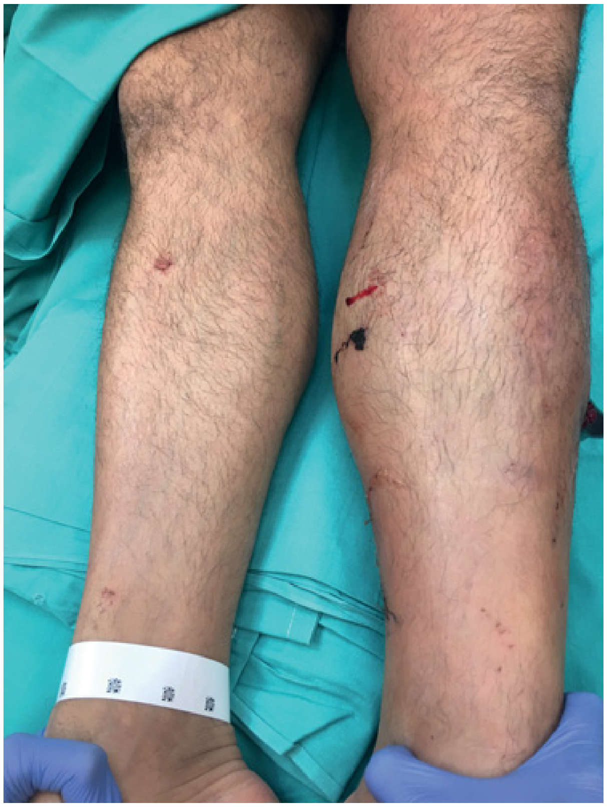


Figure 10.2 Penetrating trauma to the left lower leg with severe swelling and intense pain. This patient should be evaluated for compartment syndrome.

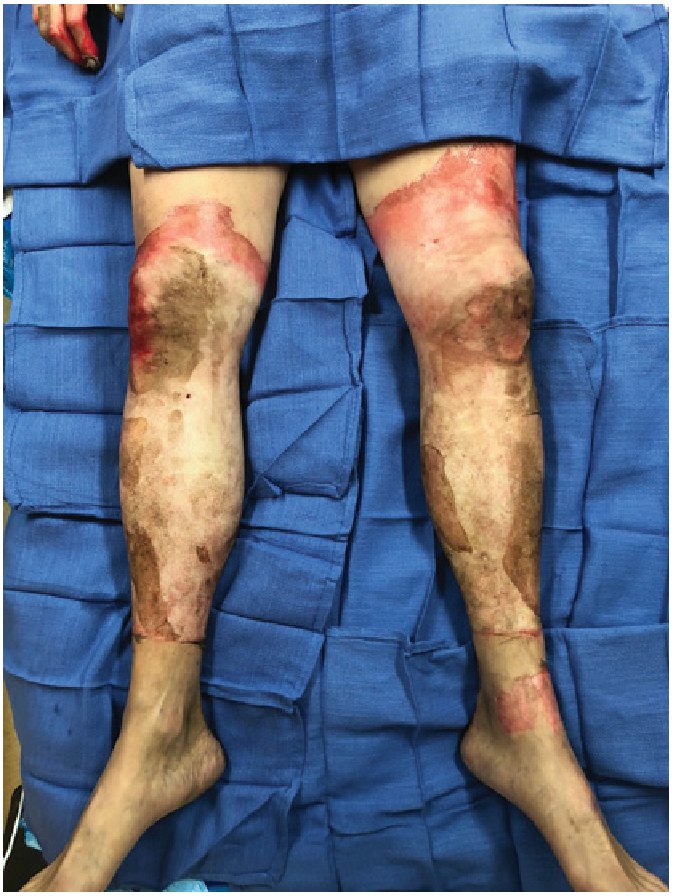


Figure 10.4 Circumferential burns of both lower extremities. These patients develop compartment syndrome and should undergo mandatory prophylactic escharotomies.

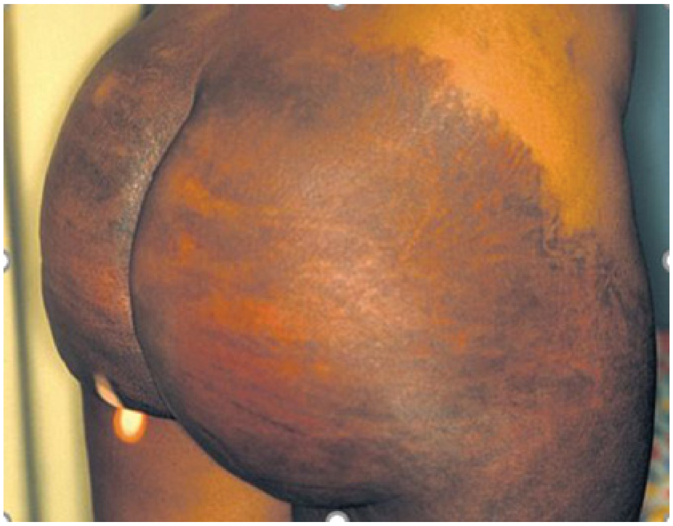


Figure 10.3 Extensive soft tissue trauma in the buttocks following a violent beating, resulting in compartment syndrome and rhabdomyolysis.

Timely diagnosis and decompressive fasciotomy are critical for limb salvage and prevention of renal failure. Muscle damage and neuropraxia may be reversible if the compartment syndrome is treated early, within four to six hours of the ischemic insult. Ischemia lasting greater than four to six hours more commonly results in irreversible muscle ischemia and axonotmesis. This ischemia can result in muscle necrosis, chronic muscle contracture, sensory deficit, paralysis, and potential limb loss. Delayed treatment of a compartment syndrome causes myoglobinemia and myoglobinuria, which might cause acute renal failure. CPK levels higher than 5,000 units/L are associated with an increased risk of renal failure, especially in elderly patients.

The lower leg is the most commonly affected site, followed by the forearm, thigh, arm, and buttocks.

Clinical Presentation

- The clinical examination is often unreliable, especially if performed during the early stages of the compartment syndrome. A high index of suspicion is the cornerstone of early diagnosis.
- The classic "six Ps" described in extremity compartment syndrome (pain, paresthesia, pallor, poikilothermia, pulselessness, paralysis) are often not present, especially at the early stages.
- Pain out of proportion, often not responding to narcotic analgesia, is the most common and earliest clinical finding. The pain becomes worse with passive stretch of the involved muscles. Paresthesia is a fairly early sign, indicating nerve ischemia. These examination findings, however, may be difficult to elicit in obtunded or otherwise unevaluable patients. For example, after traumatic brain injury or in patients requiring high levels of sedation or paralysis, these clinical exam findings may be difficult to elicit.
- The clinical finding of a tense compartment is often operator dependent. Elevated CPK levels in the absence of explanatory diagnosis should raise the suspicion of

compartment syndrome and prompt thorough physical examination and quantitative measurement of compartment pressures.

- Some of the findings, such as pulselessness, pallor, or paralysis, are late findings, when the extremity becomes less likely to be salvageable.
- In order to avoid delayed diagnosis, the evaluating physician should have a high index of suspicion and have a low threshold to request surgical or orthopedic consultation (Figure 10.5 A–C).

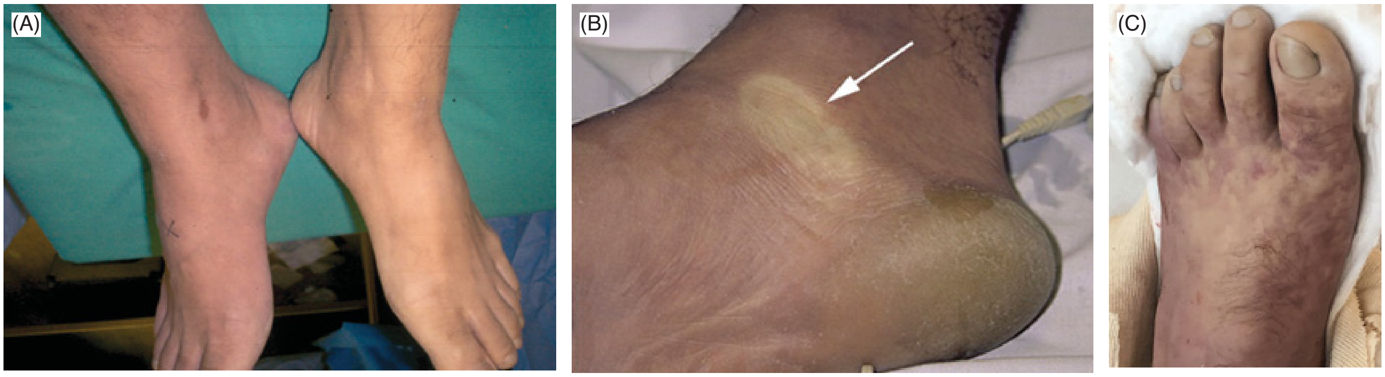


Figure 10.5 A–C Delayed diagnosis of extremity compartment syndrome: cyanotic appearance of the skin of the right foot (A), delayed capillary refill of the skin the left foot (B), and mottled appearance of the skin of the left foot (C), are late findings of compartment syndrome and are associated with a high risk of muscle necrosis and limb loss.

Investigations

- Pulse oximetry on the affected toes or fingers is normal in the early stages of compartment syndrome. An abnormal SaO2 is a late finding.
- CPK levels should be performed in patients with extensive soft tissue trauma and in cases with suspected compartment syndrome. Elevated CPK should be monitored serially for trend and prompt the physician to evaluate carefully for extremity compartment syndrome. Very high levels are suggestive of large muscle compartment involvement (e.g., gluteal, thigh compartments).
- Progression of compartment syndrome can lead to myoglobinuria in which the urine is dark, brownish, or “red” macroscopically but hematuria is absent on microscopic urinalysis. The patient may go into renal failure with elevation in serum creatinine and BUN. Muscle necrosis and renal failure may also result in hyperkalemia (Figure 10.6).

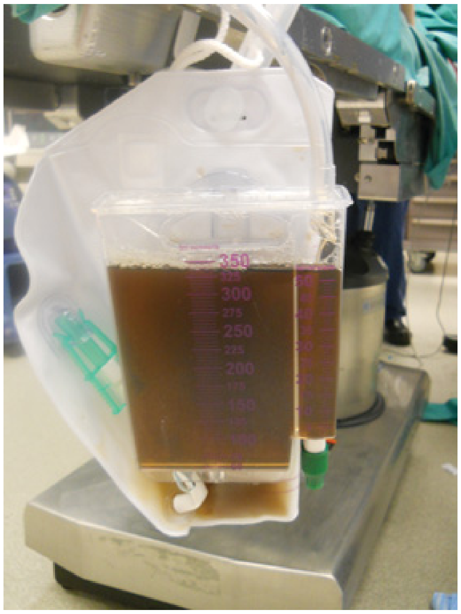


Figure 10.6 Myoglobinuria following delayed treatment of extremity compartment syndrome. The urine has a characteristic brownish or dark red appearance.

- Measurement of muscle compartment pressures is the definitive diagnostic test and should be considered liberally in suspected cases (Figure 10.7 A–C).

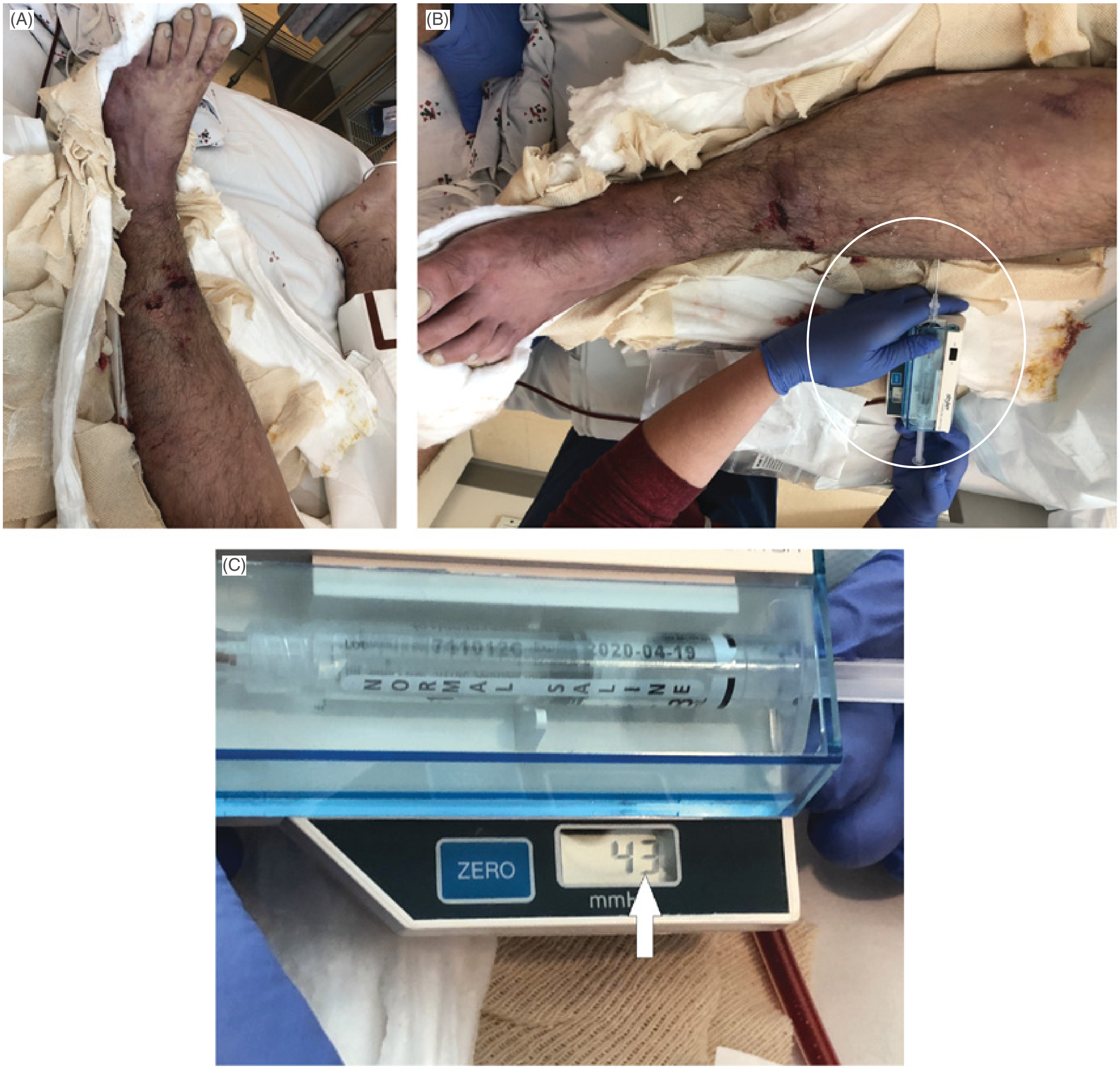


Figure 10.7 A–C Delayed diagnosis of compartment syndrome of the left lower leg, following a comminuted fracture of the tibia and fibula and cast application. The skin on the foot looks mottled and there was no dorsalis pedis pulse (A). Measurement of muscle compartment pressures shows an elevated pressure (circle; B, C).

Measurement of Compartment Pressures

- The compartment pressure can be measured with a handheld device (i.e., Stryker® device) or by connecting an 18 gauge needle placed in the muscle compartment to a pressure transducer. Good knowledge of the anatomy of the muscle compartments in each area is important for correct diagnosis and adequate fasciotomies. The pressures in *all* compartments of the suspected region should be measured. It is possible that the pressure in one compartment is normal while that the adjacent compartment is abnormal. Thus, in the lower leg, which has four compartments, four different measurements should be obtained.
- Pressure greater than 30–40 mmHg or perfusion pressure<30 mmHg is generally considered an indication for decompressive fasciotomy.

Technique for Compartment Pressure Measurement with Stryker® Device

- Assemble the device as shown (Figure 10.8 A–E).

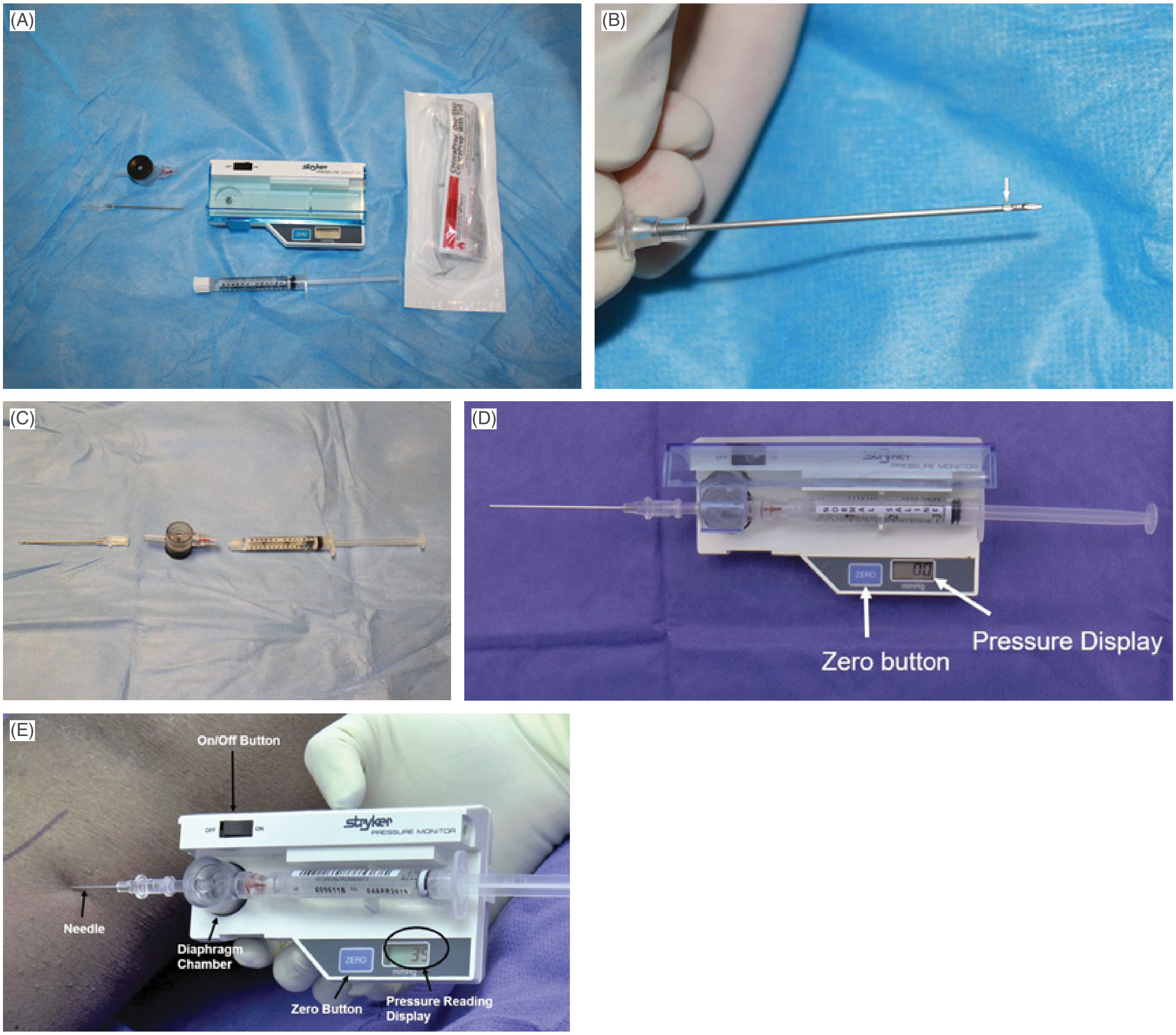


Figure 10.8 A–E Equipment for pressure measurement with a hand-held device. The pieces include the device, a prefilled syringe, a diaphragm chamber, and a side-hole needle (A). The needle used for transducing the pressure has a side-port and beveled point (B). The diaphragm is connected to the needle and the prefilled syringe (C). The assembled system is placed in the device. The "zero" button is pushed and the display should show "00" (D). The needle is inserted into the muscle, perpendicular to the skin, and after injection of approximately 0.3 ml of sterile saline, the pressure is read. In this case, the pressure was 39 mmHg (E).

- Gently flush any residual air out of the system, with 0.5 ml of sterile saline.
- Turn on the unit and "zero" the reading display by pressing the zero button. After sterilizing the overlying skin, insert the needle, perpendicular to the skin. Resistance should be felt at the level of the skin and again at the level of the fascia. Once in the desired muscle compartment, clear the needle of tissue by slowly injecting approximately 0.3 ml into the compartment. Wait several seconds for the display to equilibrate and read the pressure.
- An alternative method of measuring the compartment pressure is with an 18 gauge needle and an arterial line pressure transducer.

Compartment Pressures in the Upper Arm

- The upper arm has two compartments, the anterior and posterior compartments, separated medially by the brachial artery. During compartment pressure measurements, the arm is kept in neutral position because flexion or extension at the elbow can affect compartment pressures.
- For anterior (flexor) compartment pressures, the needle is inserted perpendicular to the skin, in the middle third of the anterior arm. For posterior (extensor) compartment pressures, the needle is inserted in the middle third of the posterior arm (Figure 10.9).

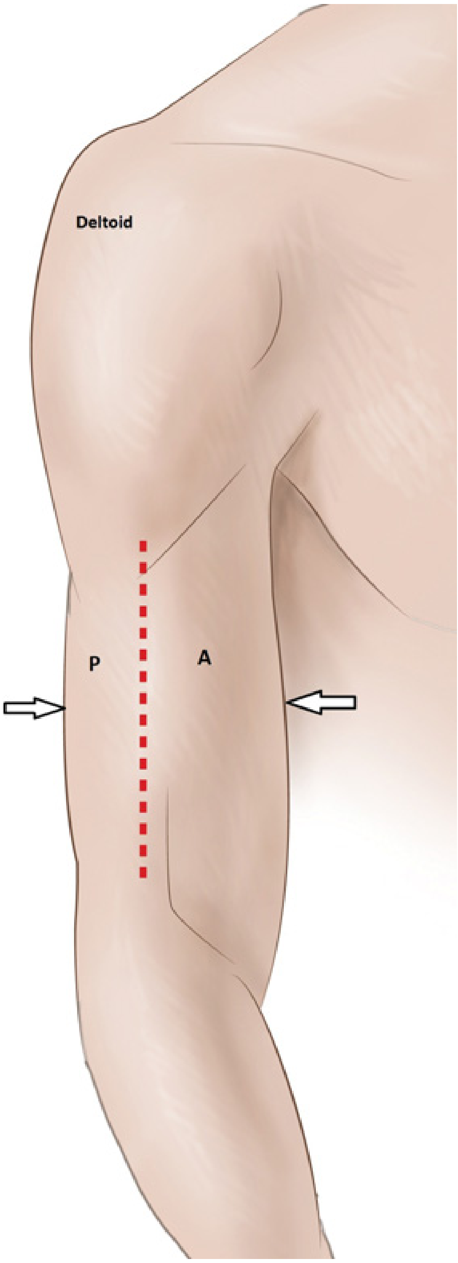


Figure 10.9 The upper arm has two compartments, the anterior (A) and the posterior (P). Compartment pressures are measured in the middle third of the arm with the needle perpendicular to the skin (tip of arrow). To measure the posterior compartment pressure, raise the arm and gently flex the forearm at the elbow to avoid overextension, which may affect the reliability of the pressure measurement.

Compartment Pressures in the Forearm

- The forearm has three compartments: the volar (flexor), dorsal (extensor), and lateral (mobile wad) compartments. The mobile wad is often grouped with the dorsal compartment. During compartment pressure measurement, the forearm is kept in neutral position.
- The flexor compartment is the most common forearm compartment to develop compartment syndrome. For pressure measurements, the needle is inserted perpendicular to the skin into the middle third of the flexor surface of the forearm. For dorsal (extensor) compartment pressure measurements, the needle is inserted in the middle third of the extensor surface of the forearm (Figure 10.10).

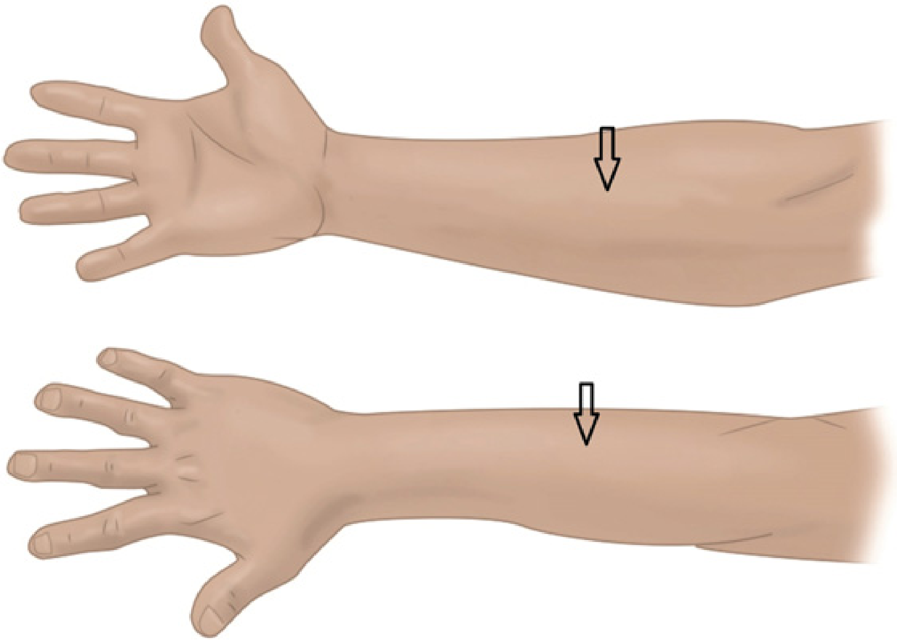


Figure 10.10 To measure the pressure in the forearm, insert the needle perpendicular to the skin in the middle third of the compartment (tip of arrow).

Compartment Pressures in the Buttock

- The buttock has two main muscle compartments, the gluteus maximus compartment and the gluteus medius/minimus compartment, which is deep to the gluteus maximus. The compartment pressures are best measured with the patient in the prone or lateral position.
- The needle is inserted into the gluteus maximus, in the lateral upper quadrant, to avoid injury to the sciatic nerve. For measurement of the pressure in the gluteus medius muscle compartment, the needle is inserted deeper (Figure 10.11).

Compartment Pressures in the Thigh

- The thigh has three muscle compartments: the anterior, posterior, and the medial compartments. The medial muscle compartment contains the femoral vessels and the femoral nerve, and it rarely develops compartment syndrome. For this reason, and because of the risk of vascular injuries, there is no need for routine pressure measurements in this compartment.
- For anterior compartment pressure measurements, the needle is inserted perpendicularly into the skin, in the middle third of the anterior thigh. For posterior compartment pressures, the needle is inserted in the middle third of the posterior thigh (Figure 10.12).

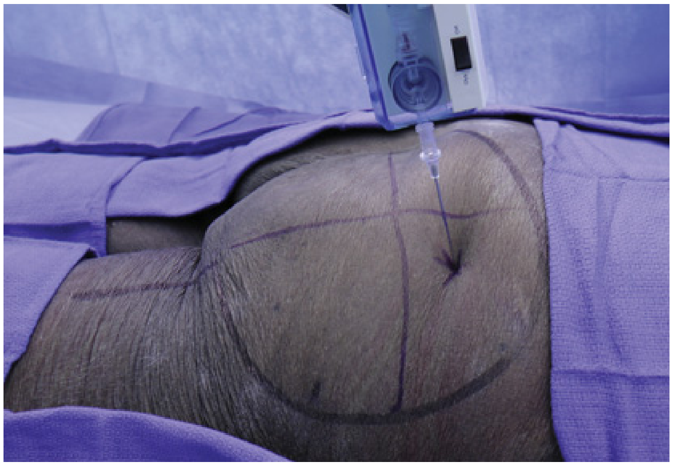


Figure 10.11 Measurement of pressures in the buttock muscle compartments. The needle is inserted perpendicular to the skin in the lateral upper quadrant of the buttock, to avoid injury to the sciatic nerve.

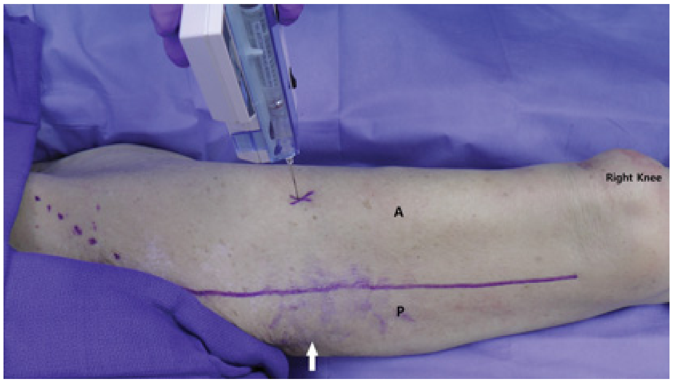


Figure 10.12 The thigh has three compartments: anterior (A), posterior (P), and medial. For pressure measurements, the needle is inserted perpendicular to the skin, in the middle third of the posterior thigh (tip of arrow).

Compartment Pressures in the Lower Leg

- The lower leg has four muscle compartments: the anterior, lateral, superficial posterior, and deep posterior compartments.
- For measurement of the anterior compartment pressure, the needle is inserted perpendicular to the skin about two fingerbreadths lateral to the anterior border of the tibia, at the junction of the upper and middle thirds of the leg.
- For measurement of the lateral compartment pressure, the entry point is about one fingerbreadth in front of a line joining the head of the fibula and the lateral malleolus (this line corresponds to the fibula) at the junction of the upper and middle thirds of the leg.
- For measurement of the superficial posterior compartment pressure, the needle is inserted in the middle of the calf, at the junction of the upper and middle thirds of the leg.
- For measurement of the deep posterior compartment pressure, the needle is inserted about one fingerbreadth posterior to the medial border of the tibia, at the junction of the upper and middle thirds of the leg (Figure 10.13 A,B).

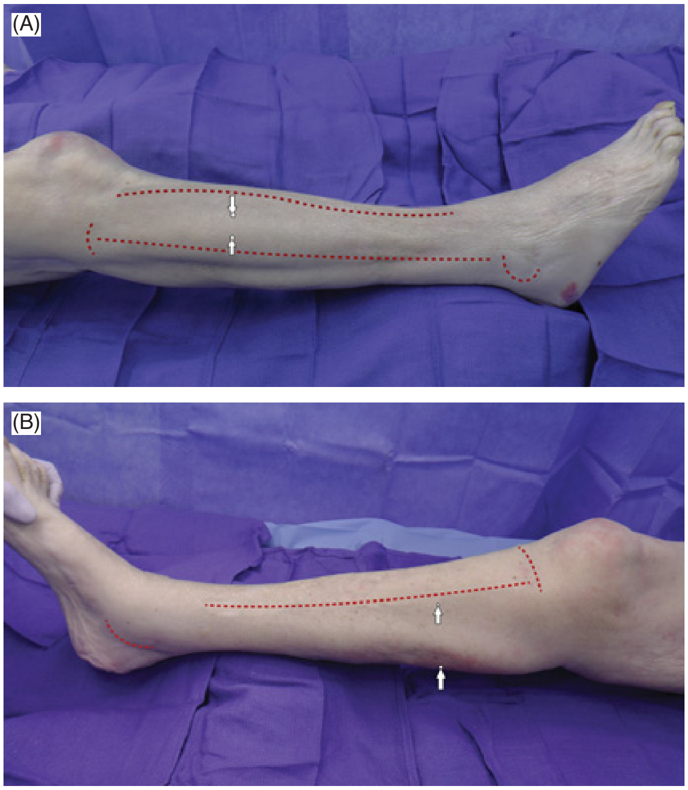


Figure 10.13 A,B Lower leg compartment pressure measurements. For measurement of the anterior compartment pressure, the needle is inserted perpendicular to the skin about two finger breadths, lateral to the anterior border of the tibia (arrow; A). For the lateral compartment, the entry point is about one fingerbreadth in front of a line joining the head of the fibula and the lateral malleolus. For measurement of the superficial posterior compartment pressure, the needle is inserted in the middle of the calf, at the junction of the upper and middle thirds of the leg (lower arrow; B). For the deep posterior compartment, the needle is inserted about one fingerbreadth posterior to the medial border of the tibia, at the junction of the upper and middle third of the leg (upper arrow).

Complications of Extremity Compartment Syndrome

- Local complications include ischemic damage to the nerves with permanent sensory deficits or paralysis.
- Muscle ischemia may result in the development of Volkmann's contractures and, in severe cases, muscle necrosis requiring amputation.
- Systemic complications, including myoglobinemia with myoglobinuria, can cause acute renal failure.
- Hyperkalemia and hypocalcemia are fairly common complications, and they should be monitored closely because of their possible cardiotoxic effect (Figure 10.14 A–C).

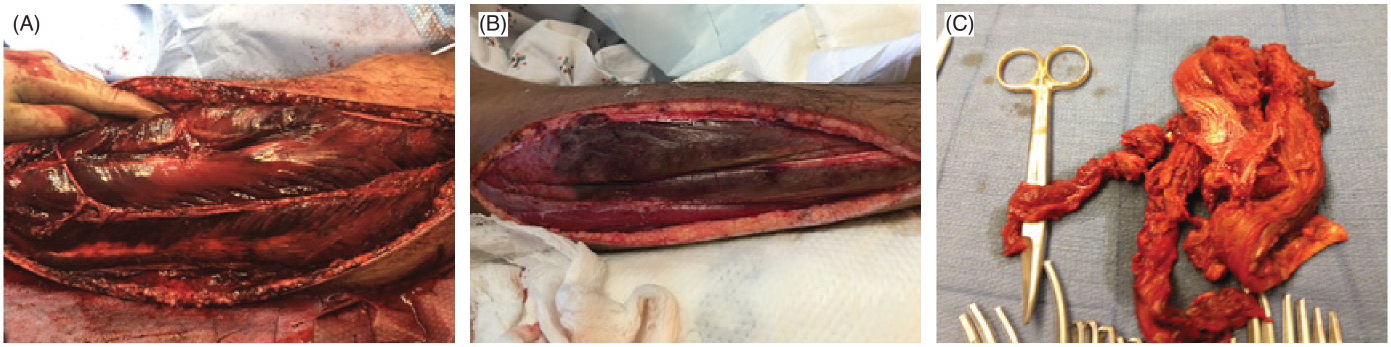


Figure 10.14 A–C Delayed treatment of extremity compartment syndrome resulting in muscle necrosis requiring excision.

Management

- Treat any reversible causes, such as removal of tight casts or bandages, escharotomy in circumferential burns, evacuation of any large hematomas, and timely repair of arterial injuries.
- Judicious fluid resuscitation, aggressive diuresis (urine output > 1ml/kg/hour), and administration of bicarbonate in cases of significant CPK elevation to maintain slightly alkaline urine are the most important therapeutic interventions to reduce the risk of acute renal failure.
- Close monitoring of urine output and judicious resuscitation is imperative, as fluid overload can contribute to compartment hypertension.
- Mannitol administration (0.5–1 g/kg over 20 minutes) may be helpful in borderline cases and might reduce the need for fasciotomy.
- Decompressive fasciotomy should be performed without delay in all cases with confirmed compartment syndrome (Figure 10.15 A,B, Figure 10.16 A,B).

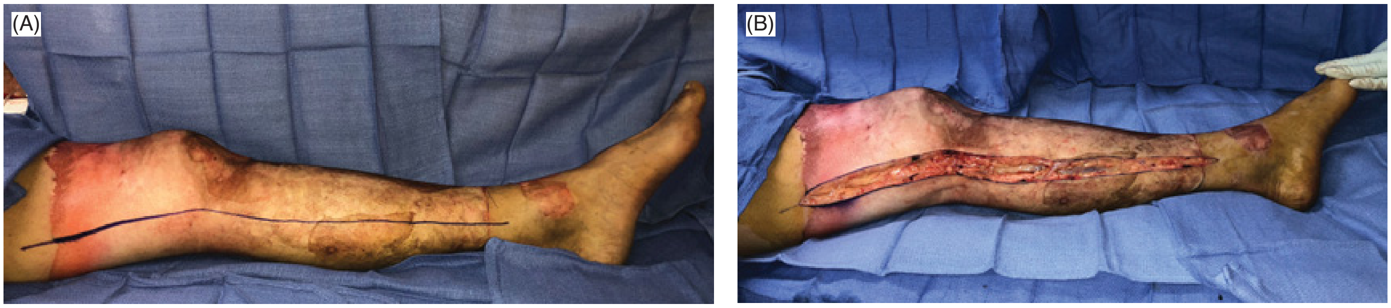


Figure 10.15 A,B Circumferential burns of the lower extremity require early prophylactic escharotomy to prevent compartment syndrome.

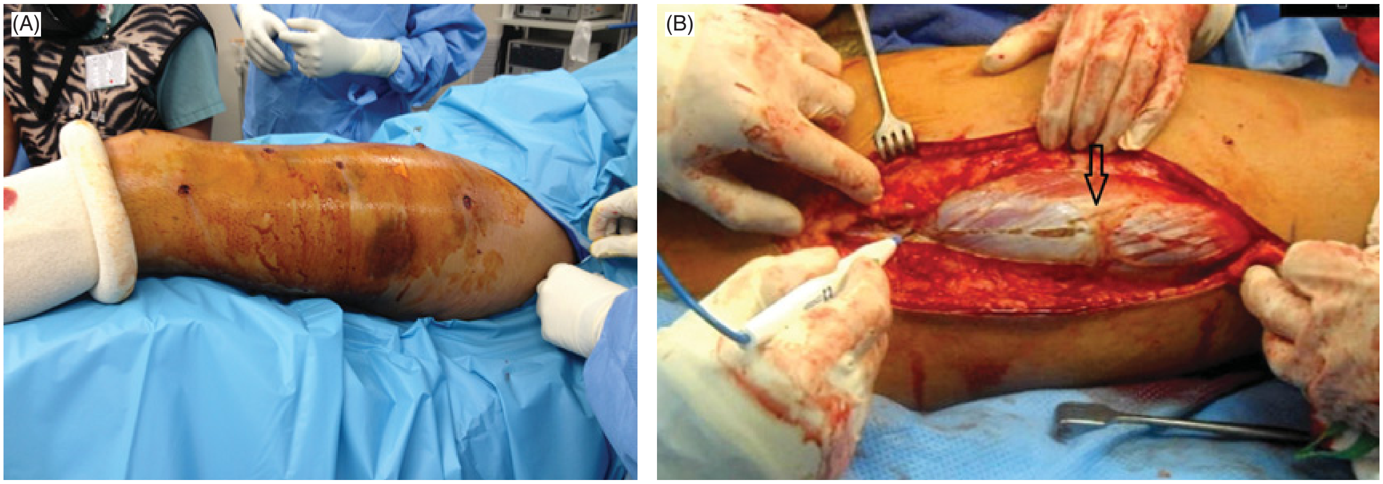


Figure 10.16 A,B Left thigh compartment syndrome following multiple gunshot wounds (A). The patient underwent an emergency fasciotomy and clot evacuation. Note the bulging muscle (arrow) after fasciotomy (B).

Tips and Pitfalls

- Delayed diagnosis is a common error. In patients at risk for extremity compartment syndrome, maintain a high index of suspicion. Serial clinical examinations, serial CPK levels, and, in the appropriate cases, direct compartment pressure measurements remain the cornerstone of early diagnosis.
- Monitor closely any at-risk compartments with casts or dressings in place, especially if the patient is pharmacologically sedated or paralyzed. Compartment syndrome may be easily missed.
- Disproportionate pain not responding to usual doses of analgesia should alert the provider to the possibility of compartment syndrome.
- Clinical examination alone can be unreliable in the diagnosis of compartment syndrome. In suspected cases, measure the compartment pressures.
- Technical errors in measuring the compartment pressures are common. Measurements should be performed liberally in suspected cases, including consideration of all compartments in the region. The pressure may be normal in one compartment and abnormal in the adjacent one.
- Poor knowledge of the anatomy of the extremity muscle compartments is a common error and may contribute to a missed diagnosis.

Chapter

11

Ballistics

Ramon Cestero, David Plurad, and Demetrios Demetriades

Definitions

Caliber: The caliber of a handgun or rifle is typically described as the diameter of the bore, although this can sometimes vary depending on how the diameter is measured. For example, a 0.38 bullet refers to a bullet that can be fired along a bore that measures 0.38 inches in diameter. The caliber is expressed in inches in the United States (e.g., 0.45 inches) or millimeter (mm) in other countries (e.g., 9 mm).

Bullet Design: Traditional bullets are made of lead, a relatively soft material that expands on impact and increases damage to the intended target as more energy is imparted. Harder bullet materials, such as lead alloy, copper, bronze, and steel, limit this mushrooming effect on impact and can therefore penetrate deeper into tissues, but may not transfer as much energy if they completely traverse the target.

(a) Jacketed Bullet: At velocities greater than 2000 feet/second (ft/sec), lead bullets begin to strip and deposit metal as they travel down the barrel, increasing the probability of jamming. To avoid this problem, a "jacket" of a harder metal such as copper or zinc can either partially or completely enclose the softer lead core. In addition, the jacket provides stability to the missile and prevents fragmentation of deformation on impact. Civilian hollow-point and soft-point bullets are only partially jacketed, leaving the lead core exposed at the tip, which can then flatten out or mushroom on impact. Hunting rifle bullets are not jacketed and deform or fragment on impact, causing extensive tissue damage. An unjacketed bullet can cause up to 40 times more tissue damage than a jacketed bullet. Military bullets, constrained in design by the Hague Convention, are completely surrounded by a metal jacket ("full-metal jacket"), thereby preventing deformation upon impact.

(b) Hollow-Point Bullet: These missiles deform on impact and increase tissue damage. They are prohibited by the Geneva Convention for military use but are common in civilian use (Figure 11.1).

(c) Scored Bullet: Scoring of the bullet promotes fragmentation on impact, which results in increased tissue damage (Figure 11.2).

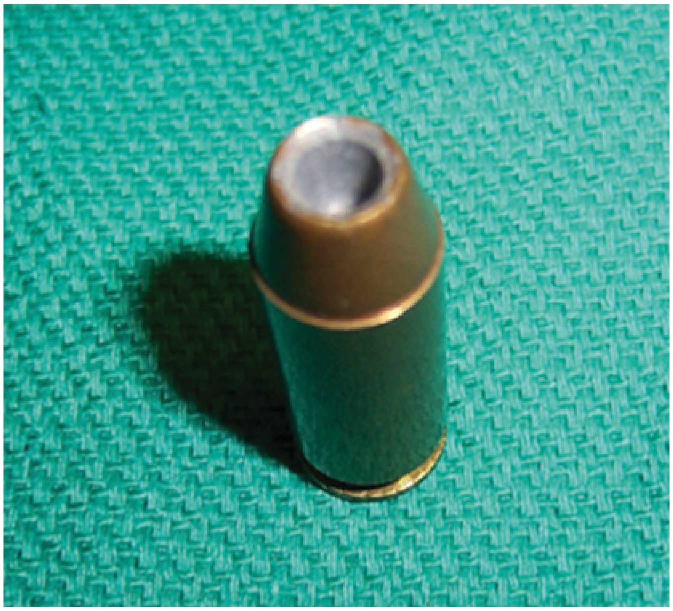


Figure 11.1 Hollow-point bullets are designed to expand on impact and transfer kinetic energy to the target.

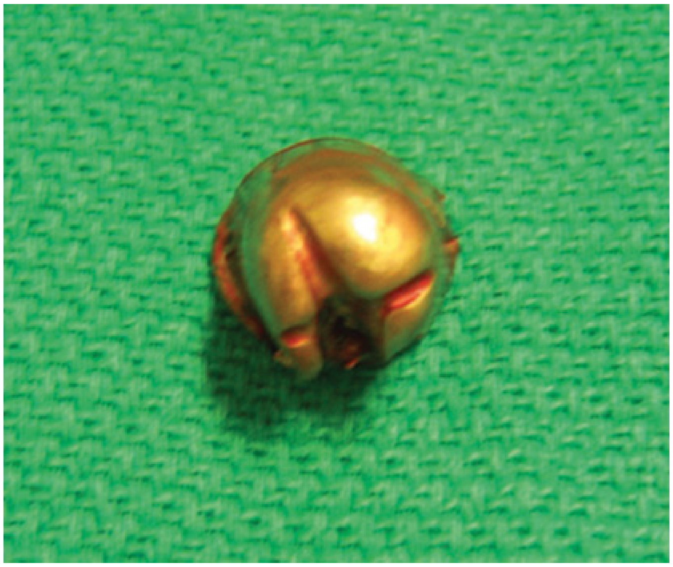


Figure 11.2 Bullet scoring promotes fragmentation on impact and increased tissue damage.

(d) “Black Talon” Bullet: The missile is covered with a copper jacket, which on impact peels back to form six sharp petals. These sharp edges can injure the exploring finger of the surgeon during attempts to remove the bullet. PDX 1 bullets are similar and are used by law enforcement in the United States (Figure 11.3 A–D).

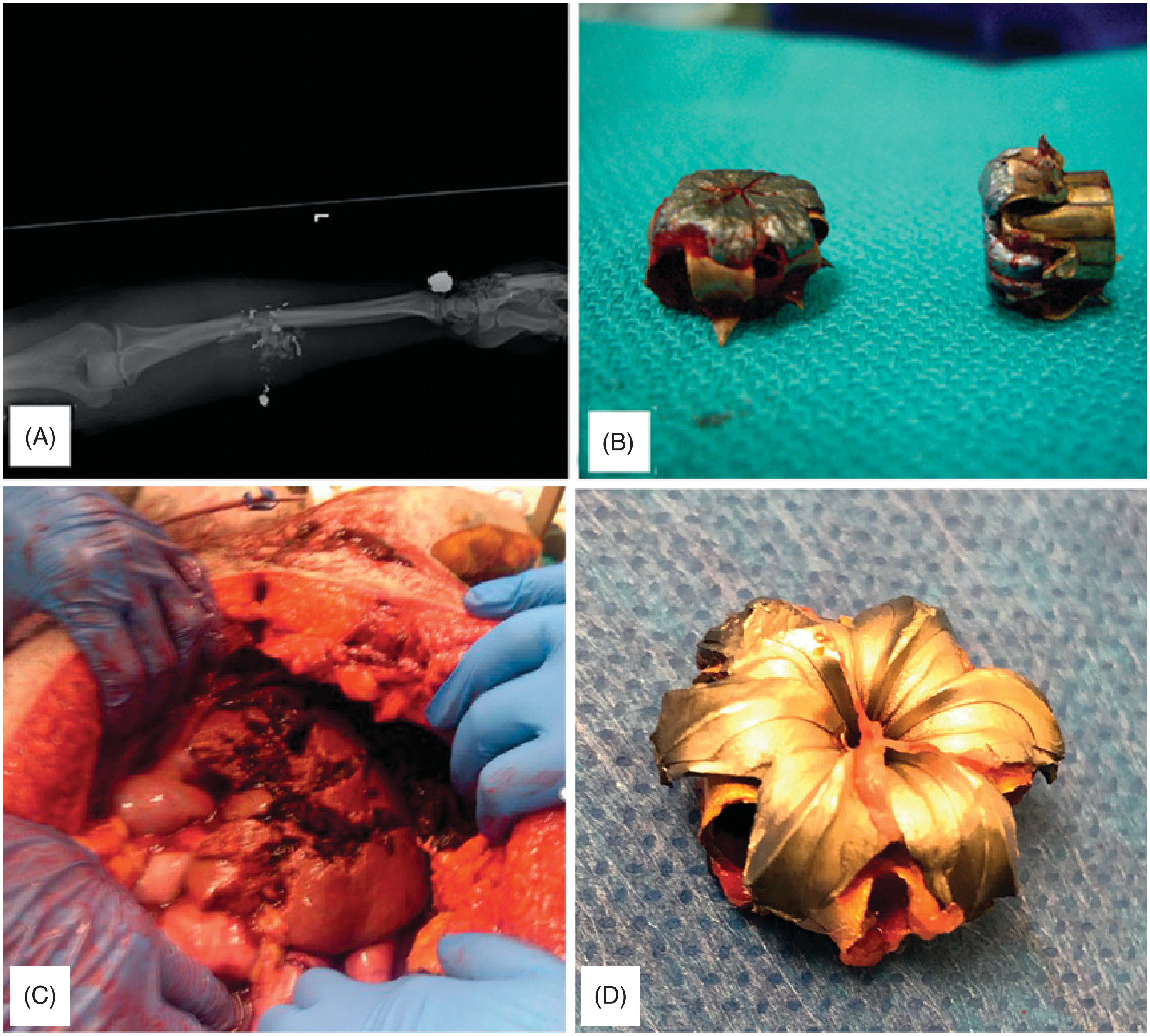


Figure 11.3 A–D Victim with gunshot wounds with PDX 1 bullets. Left forearm X-ray with resultant fracture of the radius and ulna (A). Bullets removed from the victim. The copper jacket peels back into six sharp petals upon impacting tissue, causing more tissue damage. The sharp petals may cut the exploring finger of the surgeon during the operation (B). Patient shot with PDX 1 bullet, resulting in massive liver injury (C). Bullet recovered intraoperatively. Note the sharp pedals that increase the tissue damage (D).

(e) PTFE (Teflon)-Coated Bullet: Teflon-coated bullets are designed to reduce the wear on the barrel and to decrease the chance of ricochet, and are more likely to penetrate bulletproof vests (popularly called “cop killers”). Armor-piercing designs, in which the bullet core is made of a hard substance such as depleted uranium or steel, are sometimes coated in Teflon and are not available for civilian use.

(f) Explosive Bullet: The bullet tip contains a small cavity filled with a small amount of explosive and explodes upon impacting a hard surface, such as bone. It often fails to explode and there is a risk of subsequent explosion during manipulation by the surgeon.

Bullet Velocity refers to the velocity of the missile at the muzzle of the gun and plays a critical role in the amount of inflicted tissue damage. The kinetic energy of missiles is determined by the mass of the projectile and its velocity. However, the degree of tissue destruction is not always proportional to the speed of the missile. The damage is proportional to the energy released into the tissues. Often the missile passes through the tissues without any major release of energy and results in only modest damage. Ballistics studies have shown that an AK-47 bullet releases its maximum energy only after traveling 25–30 cm into the tissues. If this bullet travels through a thin anatomical structure (e.g., the forearm), without hitting a bone, it might cause fairly limited damage.

Low-Velocity Projectiles

Low-velocity bullets (<1000 ft/sec or <340 meters [m]/sec) are commonly used in civilian firearms (handgun 9 mm at 280 m/sec, handgun 0.45 in at 255 m/sec). These bullets cause damage by direct crushing and laceration of tissues in the path of the missile. This path of destruction is referred to as the "permanent cavity." Secondary injuries can occur as the bullet fragments or impacts bone, converting them into secondary missiles (Figure 11.4, Figure 11.5 A,B, Figure 11.6 A,B).

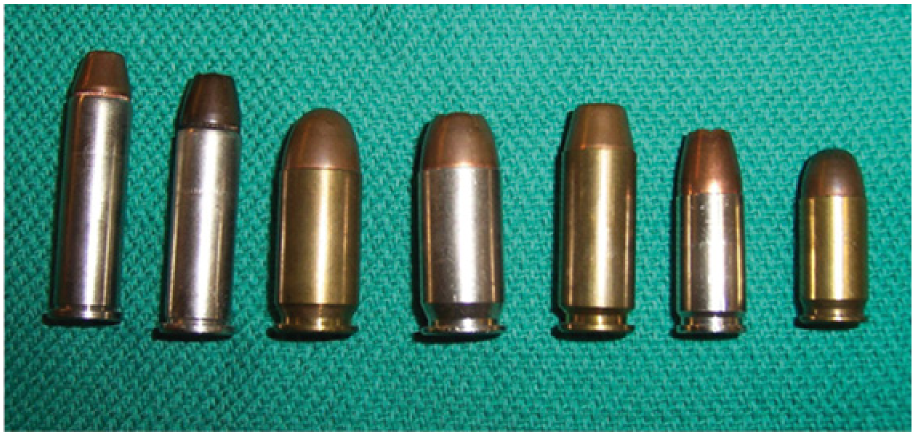


Figure 11.4 Examples of low-velocity bullets used in handguns, including hollow-point bullets.

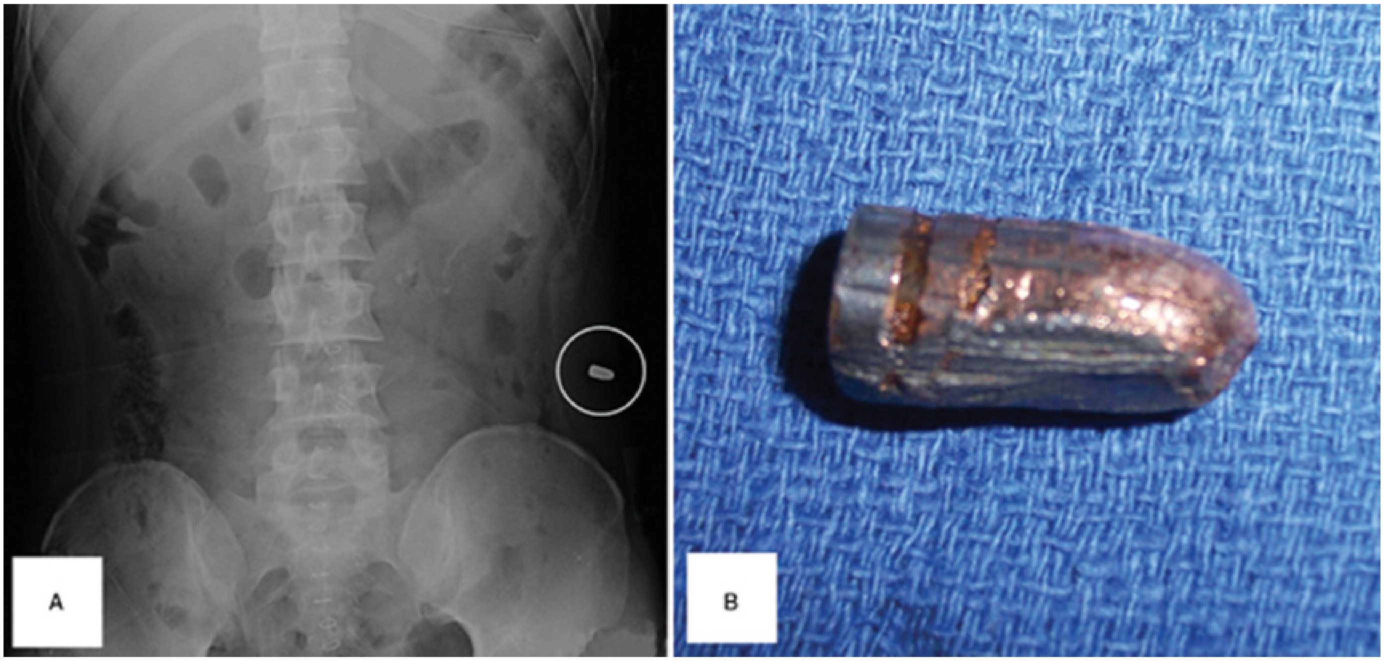


Figure 11.5 A,B Radiological appearance of non-fragmented and not deformed low-velocity bullet (A). Bullet recovered at operation (B).

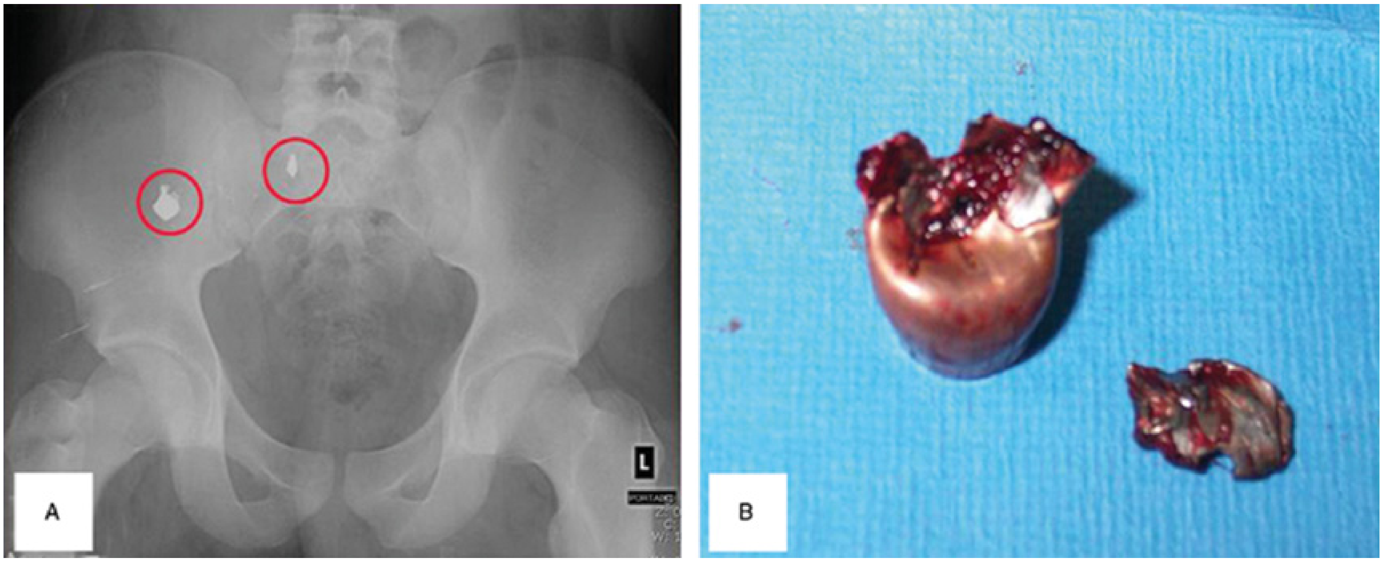


Figure 11.6 A,B Bullet fragmentation. Radiological appearance (A) and fragments after surgical removal (B).

The entrance wound is often characterized by an "abrasion ring" that develops at the edges of the skin defect and is typically round in appearance. This is caused as the bullet abrades the epidermis at the edges of the bullet path, leaving a reddish-brown circumferential ring on the damaged skin. This ring may develop irrespective of range, but it does not appear on palms, soles, axilla, and scalp. In comparison to entrance wounds, exit wounds generally tend to be larger and more irregular in shape. As a bullet travels through the body, it tends to deform and tumble, so a larger area of the bullet is presented at the skin as it exits. This causes an irregularly shaped wound at the skin surface (Figure 11.7 A,B, Figure 11.8). However, despite entrance and exit wounds having some individual unique

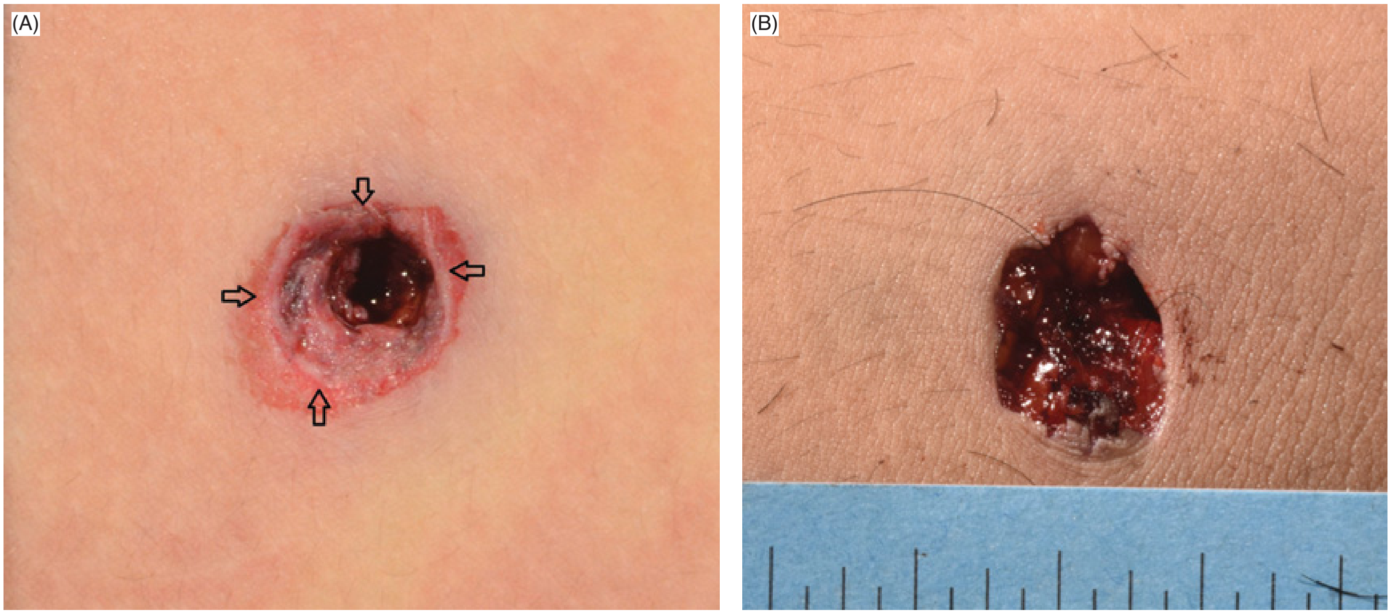


Figure 11.7 A,B Close-up image of entry site of a low-velocity gunshot wound, with erythematous abrasion ring at the edges of the circumferential wound (A). Close-up image of the exit wound (B). Note the larger and irregular edges caused by the tumbling bullet.

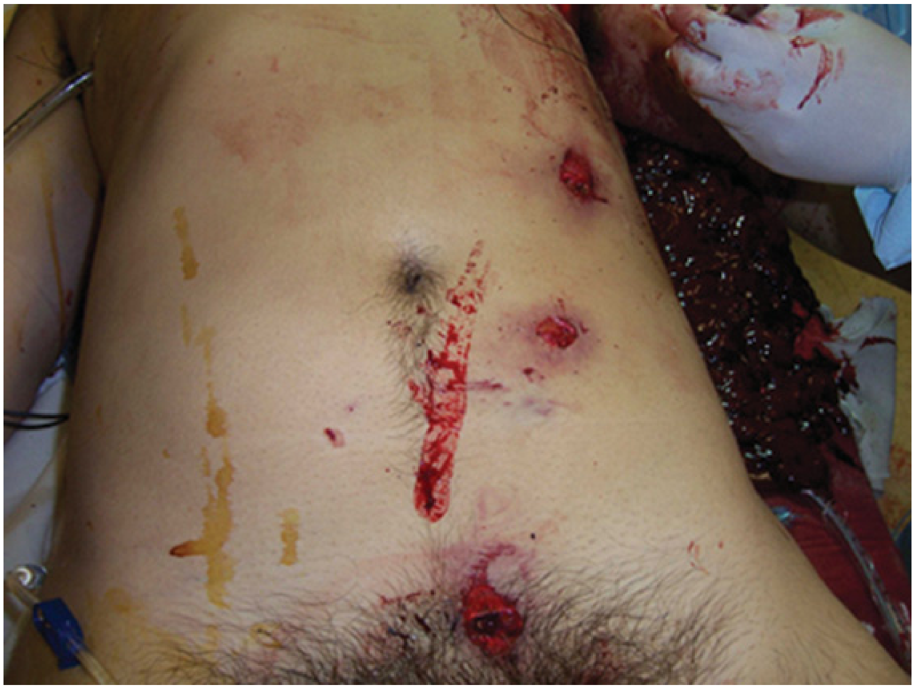


Figure 11.8 Multiple low-velocity gunshot wounds to the anterior abdomen. The wounds do not need debridement and they should not be sutured.

visual characteristics, frequently they cannot be differentiated on visual examination alone. From a medicolegal point of view, the physician should describe the appearance of all wounds, ideally with photo documentation, avoiding any characterization of a wound as entry or exit.

Assessment of all missile injuries, irrespective of velocity, includes physical examination and radiologic studies (X-ray, CT scan, CT angiography, or catheter angiography), in order to determine the bullet path, fragmentation, and injuries to the underlying organs, bones, or neurovascular structures. Wound management includes washout, tetanus prophylaxis, and a clean dressing. There is no need for surgical debridement, and the wound should not be sutured because of the high incidence of infection (Figure 11.8).

High-Velocity Projectiles

High-velocity missiles (>1000 ft/sec or 340 m/sec) are mainly used by the military, but they are not uncommon in urban civilian injuries (AK-47 rifle at 1,130 m/sec, M-16 rifle at 1,100 m/sec, 0.347 handgun at 423 m/sec) (Figure 11.9).

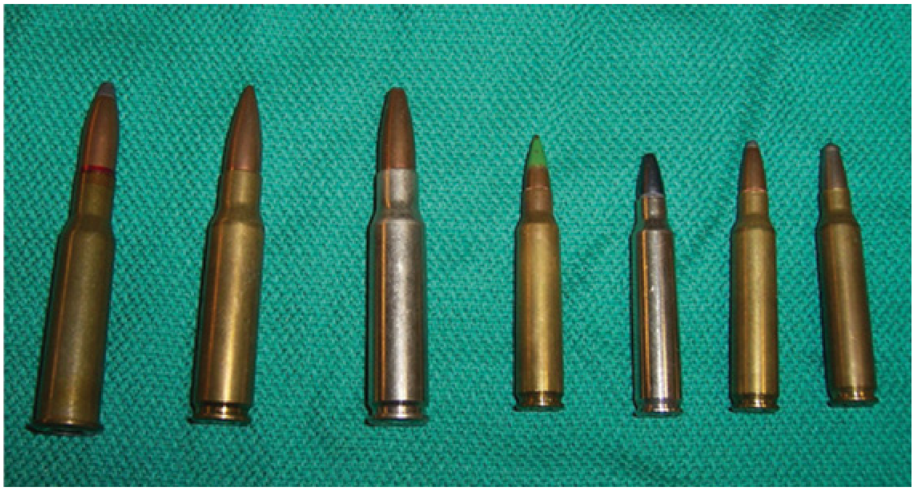


Figure 11.9 Examples of high-velocity bullets typically used in military and hunting weapons. Note the jacketing used to prevent lead stripping as the bullet travels down the barrel.

They cause much more extensive tissue destruction than low-velocity missiles, and the mechanism of injury is more complex. High-velocity bullets travel straight without any tumbling. However, some bullets (AK-47, M-16) flip once (180 degrees) when they hit the tissues and then travel backward (Figure 11.10).

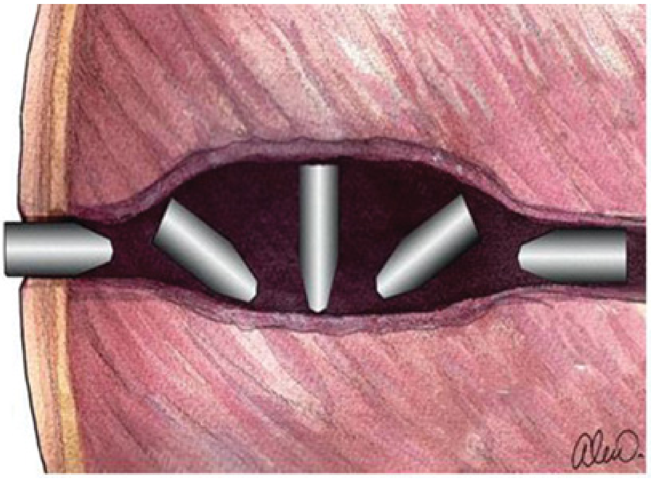


Figure 11.10 Some high-velocity bullets (AK-47, M-16) flip once (180 degrees) when they hit the tissues and then travel backward. This tumbling increases the tissue damage.

This tumbling increases the tissue damage. In addition to the direct crushing and laceration (as with low-velocity missiles), high-velocity missiles also cause damage laterally along their path by transient cavitation. During cavitation, tissues are essentially pushed in an outward fashion for a few milliseconds as the bullet travels, causing a temporary cavity, which can be up to 10 times larger than the diameter of the bullet. Solid organs, such as bone, liver, kidneys, and spleen, are more susceptible to cavitation than hollow or air-containing organs (Figure 11.11 A,B, Figure 11.12 A–C). The role of the supersonic or shock wave of the high-velocity missiles in tissue damage is not clear. As the bullet travels through tissue,

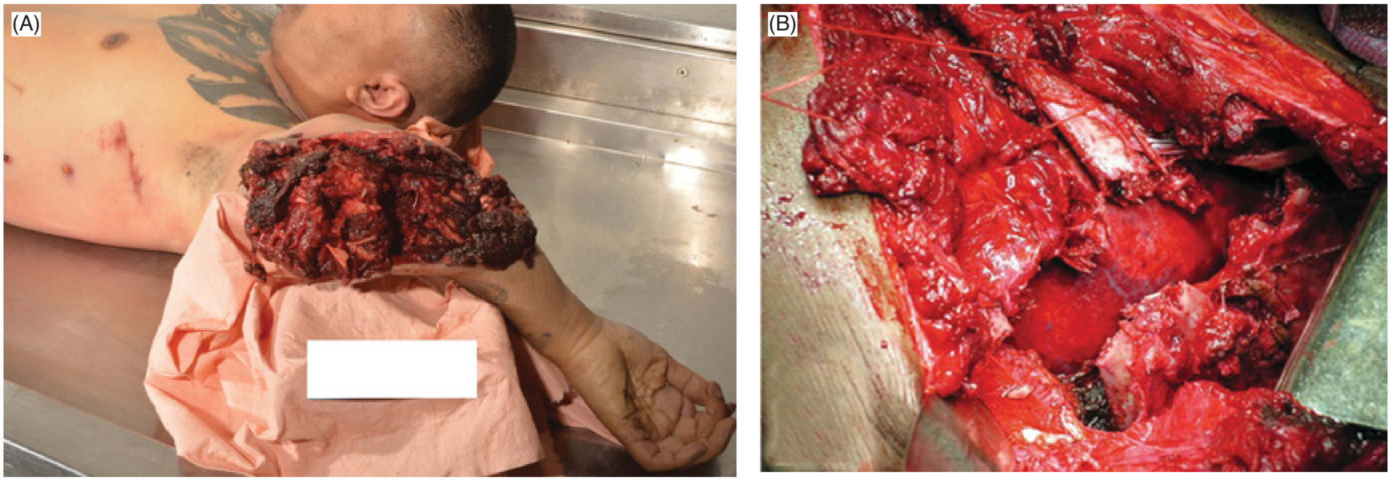


Figure 11.11 A,B High-velocity injury to the left elbow with assault rifle. Note the extensive tissue destruction (Image courtesy of Dr. Matthew Miller; LA County Coroner Office) (A). High-velocity gunshot wound to the chest with extensive soft tissues and rib destruction. The lung is exposed (B).

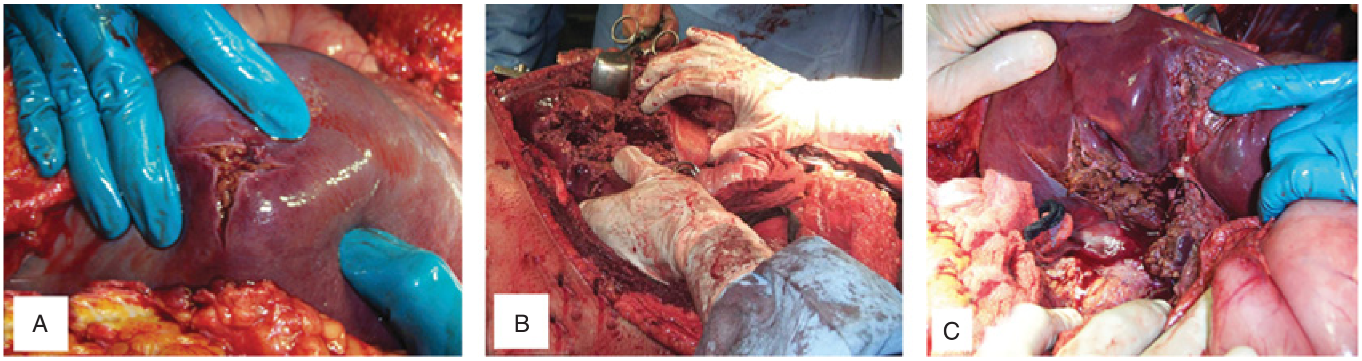


Figure 11.12 A–C Comparison of injuries from low-velocity (A) versus high-velocity gunshot wounds (B, C) to the liver. Note the increased amount of liver damage and tissue destruction from high-velocity projectiles compared to the much less severe injury from a low-velocity bullet.

rapid pressure changes are generated which can potentially damage surrounding organs. Although this is debatable, there is some evidence directly linking traumatic brain injury and pressure waves.

The management of high-velocity bullet wounds includes debridement of obviously devitalized tissue, removal of foreign material, copious irrigation, antibiotics, and tetanus prophylaxis. Some surgeons recommend routine extensive surgical debridement, while others are more conservative. The treatment should not be based exclusively on the information that a high-velocity bullet was the wounding mechanism. Even ballistic experts often cannot distinguish between low- and high-velocity injuries. It is essential to individualize the care of each patient and "treat the wound, not the velocity." It is important to leave wounds open and avoid primary closure, as these wounds almost always become infected due to the amount of tissue damage. Frequent reexamination of the wound is recommended, as devitalized tissue can become infected or necrotic over the ensuing days after injury (Figure 11.13 A,B).

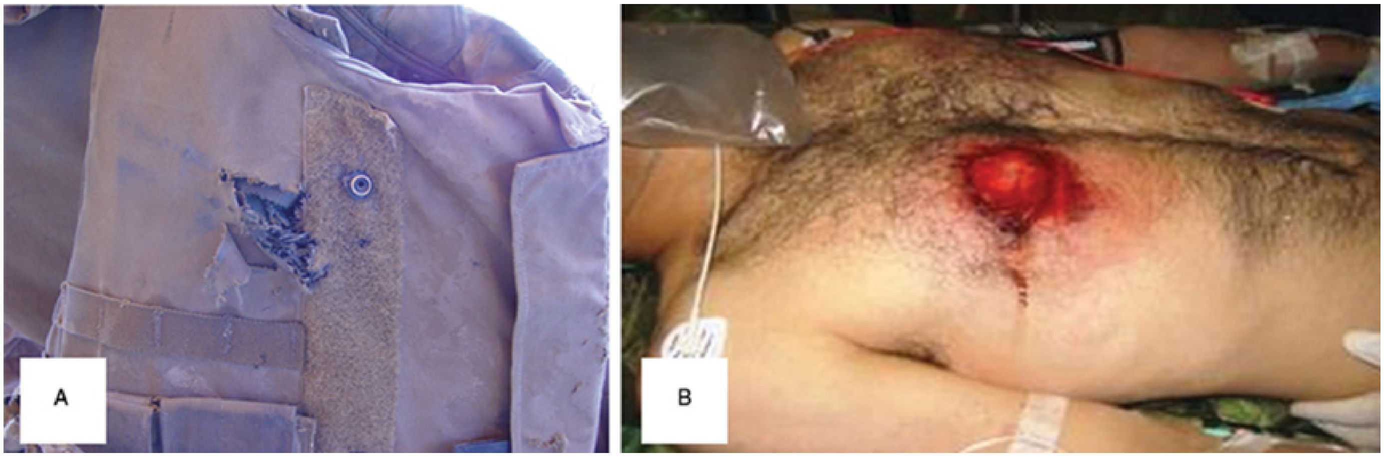


Figure 11.13 A,B Ballistic vests are made from multiple layers of strong woven fibers. The layers are designed to "catch" a bullet, thereby deforming it, and dissipating its energy to a larger area of the vest. Ceramic plates are added to ballistic vests to afford protection against high-velocity rounds (A). Blunt injuries can occur beneath the vest as the body absorbs the remaining energy from the round (B).

Shotgun Injuries

Whereas handguns and rifles fire a single bullet down a grooved (rifled) barrel, shotguns have a smooth bore and can fire up to several hundred pellets at a time.

The term "gauge" refers to the weight of a lead ball, in fractions of a pound that would have the same internal diameter of the barrel. Therefore, a 12-gauge shotgun has an internal barrel diameter that would fit a lead sphere weighing 1/12th of a pound. Shotgun shells are constructed of a plastic case filled with primer, wadding (paper and plastic which provides a gas seal), and the corresponding shot (birdshot or buckshot) (Figure 11.14 A,B). As indicated by the name of the

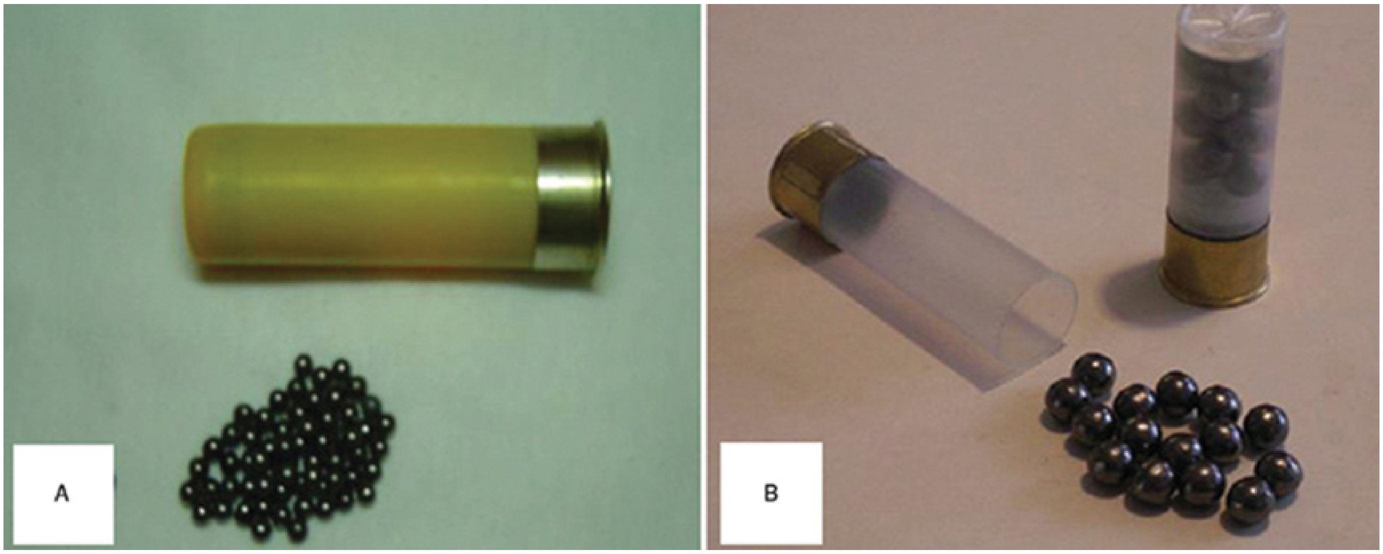


Figure 11.14 A,B Shotgun injuries. Birdshot shells (A). Buckshot shells (B).

intended target, birdshot pellets are smaller in size than buckshot pellets. Shotguns can also fire large slugs, which are designed for hunting large animals.

The distance from the shotgun to the point of impact and the length of the barrel are major determinants of the magnitude of injury (Figure 11.15 A–C).

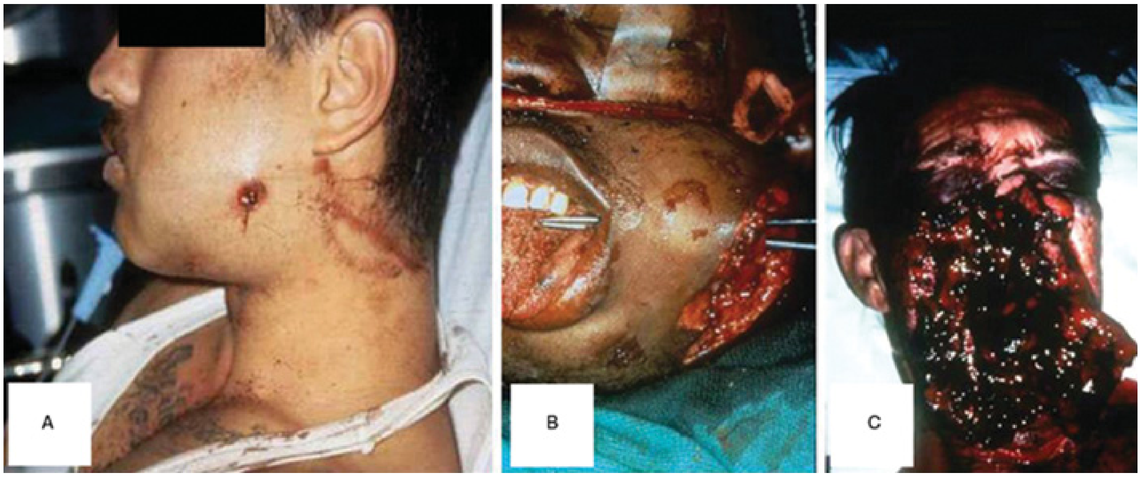


Figure 11.15 A–C Gunshot and shotgun injuries to the face. Low-velocity gunshot wound with minimal tissue damage (A). High-velocity gunshot wound with extensive tissue damage (B). Close-range shotgun injury with massive tissue destruction (C).

Since the muzzle velocity of shotguns is close to 500 m/sec, these injuries can cause a devastating amount of tissue damage at close range. At very short distances (<2 meters), the entire shot charge (along with the wadding) is deposited into the wound, causing severe trauma and typically resulting in a single-hole wound with massive underlying destruction. Powder tattooing, in which the still burning gunpowder embeds in the skin, may be seen around the wound edges (Figure 11.16 A–C).

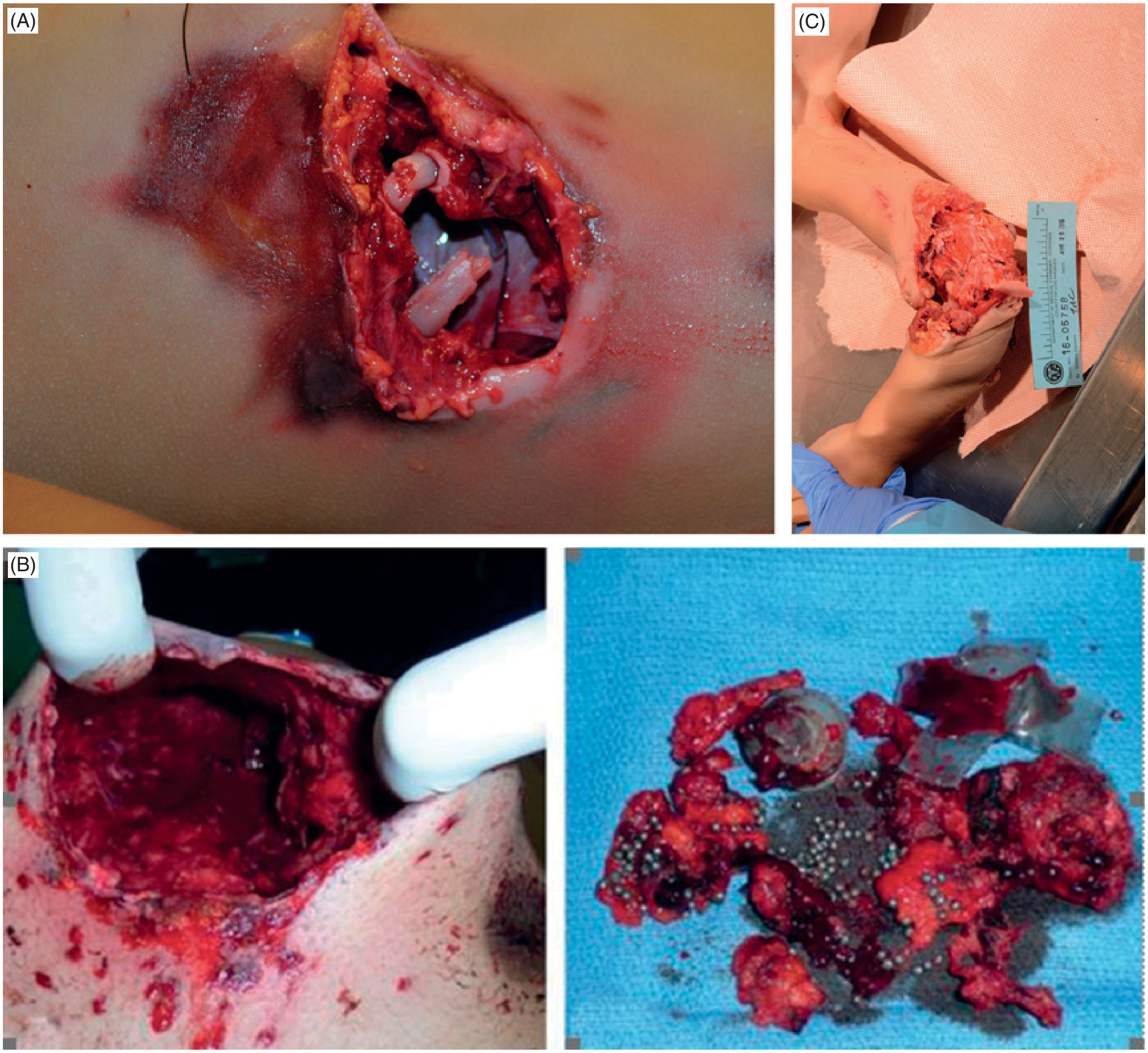


Figure 11.16 A–C Close-range shotgun wound to the chest with extensive soft tissue and ribs damage and with wadding embedded in the soft tissues (A). Close-range shotgun wound to the shoulder with significant tissue loss (B). Note the wadding and numerous pellets that were removed from the subcutaneous tissues and the underlying muscles. Close-range shotgun wound to the right elbow, resulting in massive soft tissue destruction. (Image courtesy of Dr. Matthew Miller; LA County Coroner Office) (C).

At ranges between 2 and 6 m, there is still significant destruction, but the degree of injury decreases as distance increases. The diameter of the circular wound gradually enlarges until a distance is reached where individual pellets separate from the main charge and can be seen individually entering the skin (Figure 11.17 A–C). Due to a significant loss of kinetic energy at greater distances (>6 m), shotgun injuries cause fairly limited tissue damage.

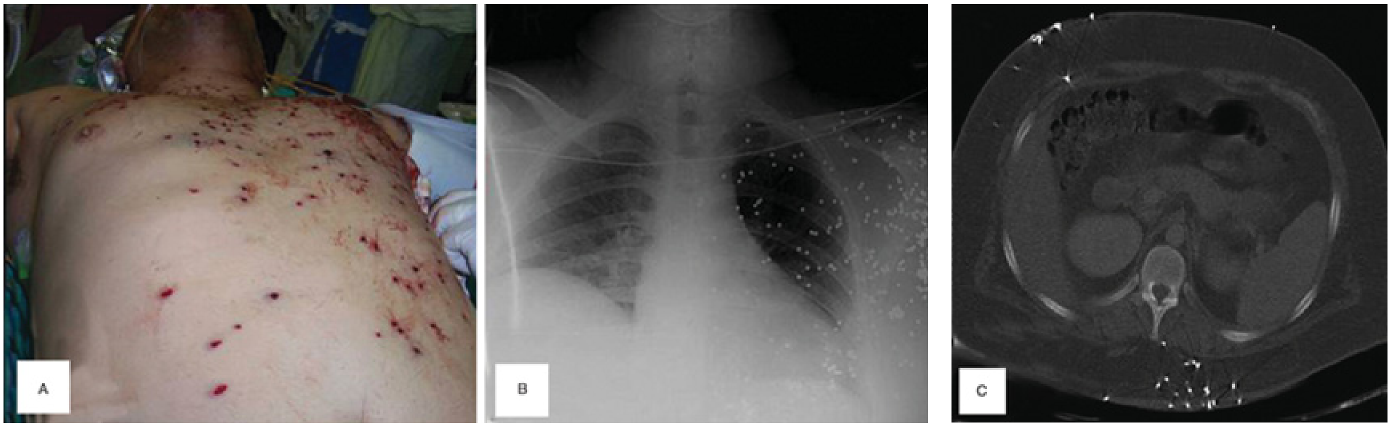


Figure 11.17 A–C Long-distance (>6 m) shotgun injuries cause minor or modest damage and the pellets often remain in the skin. Shotgun injury to the chest and abdomen from a long distance (A). There is significant spread of the pellets, and the damage to the tissues is superficial. The chest X-ray shows the spread of the pellets (B). The abdominal CT scan shows no intraperitoneal involvement (C).

Sawn-off shotguns are often used in order to conceal the weapon. In this situation, the pellets lose most of their velocity and, at distances >4 m, cause minimal tissue damage (Figure 11.18 A,B).

Due to the multiple pellets involved, X-ray and CT angio evaluation should be part of the routine evaluation of shotgun injuries, as each missile can cause injury along its individual path. Catheter angiography should be considered if vascular injury is a potential concern, such as in extremity or neck injuries (Figure 11.19 A–C). The pellets may cause artifact with CT evaluation.

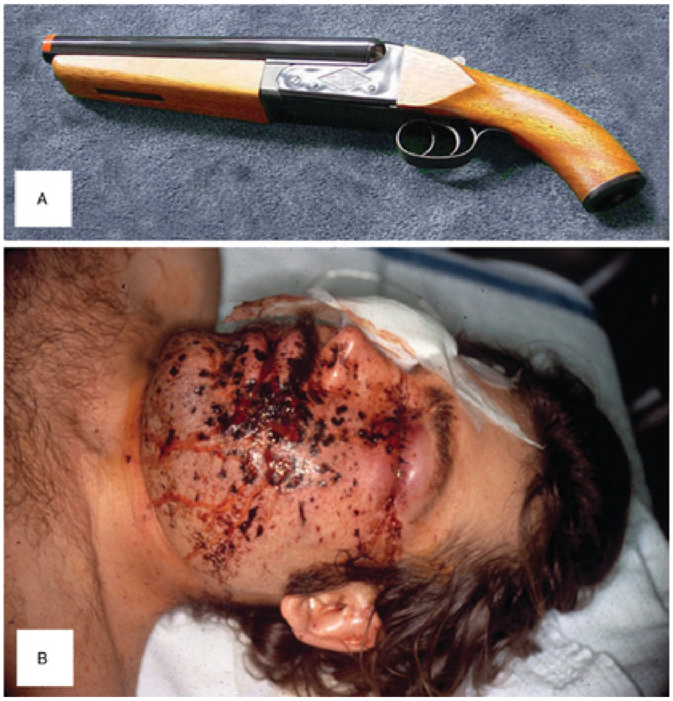


Figure 11.18 A,B Sawed-off shotgun injuries. The pellets lose most of their energy and, at distances >4 m, they cause minimal damage. Sawed-off shotgun (A). Sawed-off shotgun injuries to the face from a distance of a few meters (B). Note the minor soft tissue damage.

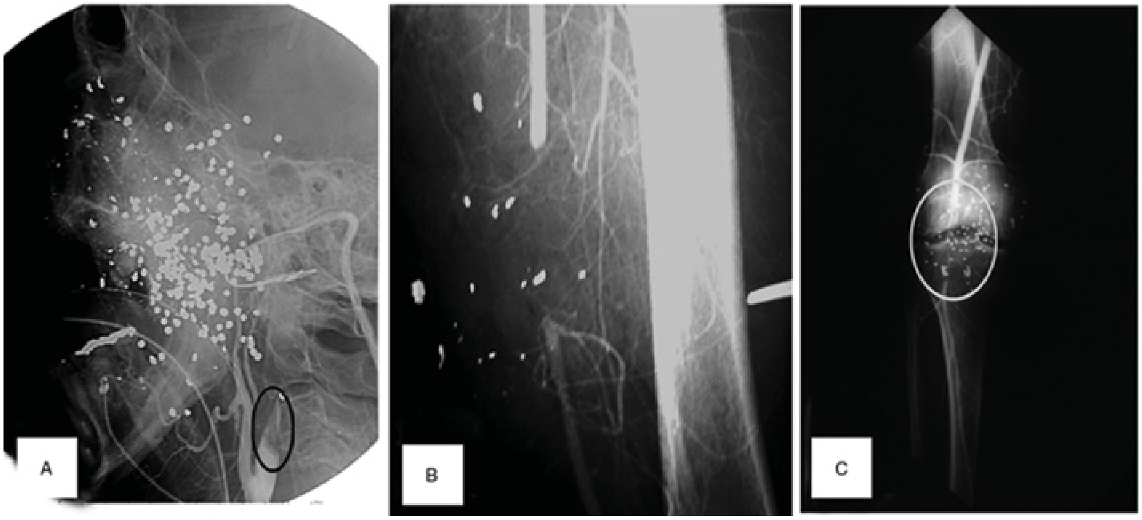
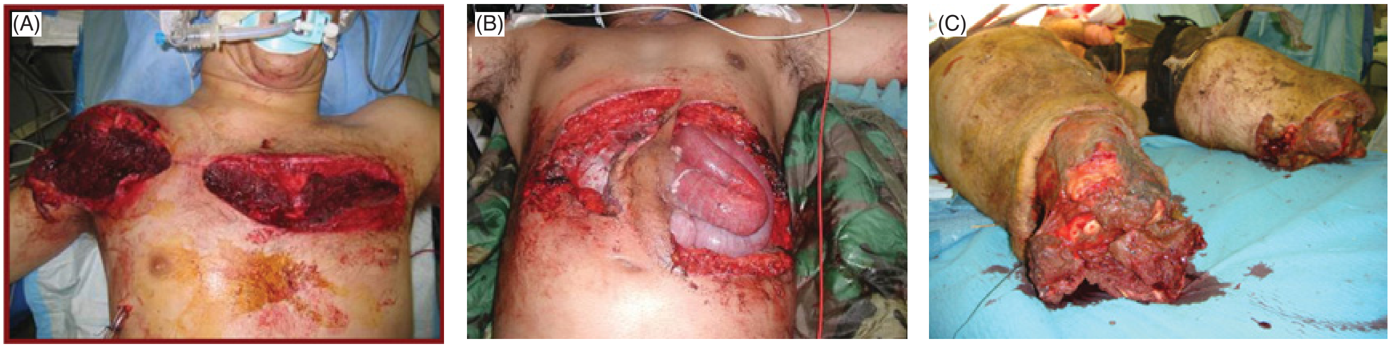


Figure 11.19 A–C Shotgun injuries in the neck or extremities should be evaluated by formal angiography to rule out vascular trauma. The angiogram shows injury and thrombosis of the left internal carotid artery (A). Angiogram shows injury and thrombosis of the superficial femoral artery (B). Angiogram shows injury to the popliteal artery (C).

Close-range wounds require extensive surgical debridement and open gauze packing. No reconstruction should be considered in the acute stage. Long-distance injuries to the soft tissues do not require any specific local treatment, and no attempts should be made to remove deep-located pellets.

Blast Injuries

Explosions have the capacity to cause a wide variety of injuries and are typically divided into five categories (Figures 11.20 A–C):



Figures 11.20 A–C Blast injuries with destructive injuries to the chest, abdomen, and lower extremities.

1. Direct injuries from high-velocity bomb fragments.
2. Blast wave injury, which is caused by the direct wave pressure effect on tissues, affecting mainly air-filled structures. This direct-pressure effect is augmented in enclosed spaces, causing more severe injury. Ears are most often affected, followed by the lungs and gastrointestinal tract. The lung injuries are often devastating, and air embolism is often a cause of death.
3. Injuries due to objects from the explosion that become missiles.
4. Tertiary blast injury, seen when individuals are thrown through the air by the explosion, striking walls and other objects, causing blunt trauma. Tertiary injuries also describe those due to structural collapse upon the patient.
5. Quaternary (or miscellaneous) blast injury is made up of all other injuries resulting from the explosion, such as burns from associated fires.

Improvised Explosive Devices

The majority of blast injuries in current military conflicts are due to improvised explosive devices (IEDs). An IED is a "homemade" explosive device commonly used in modern military conflicts by nonconventional forces. IEDs can use homemade explosives, military explosives, or commercially available materials. There are three main categories of IEDs: package type IEDs, vehicle-borne IEDs (VBIEDs), and suicide bomb IEDs. Injuries are similar to those seen in explosions, and these can be the result of both blunt and penetrating trauma. Penetrating injuries predominate due to fragmentation of the device casing itself or materials added to the device (Figure 11.21 A–C, Figure 11.22 A,B, Figure 11.23, Figure 11.24 A,B, Figure 11.25 A,B, Figure 11.26 A,B).

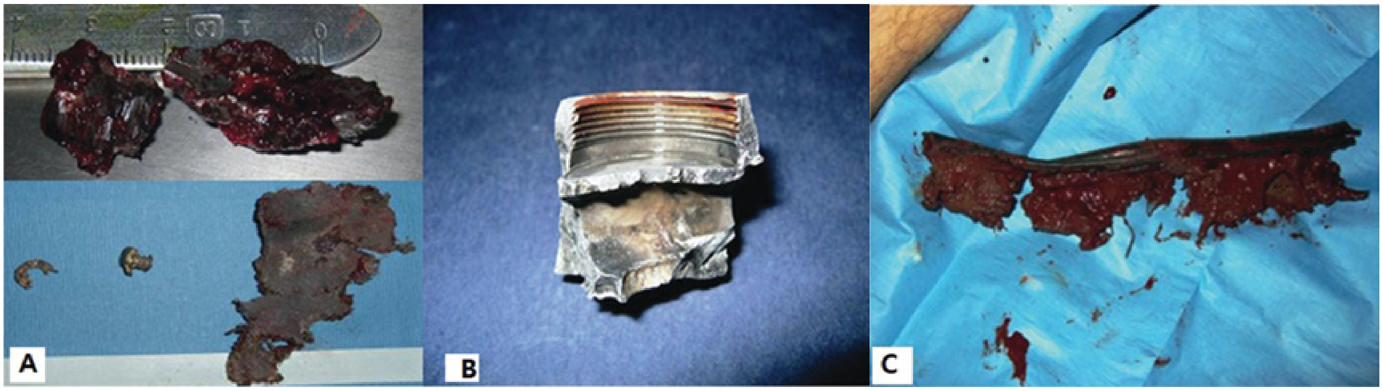


Figure 11.21 A–C Most injuries due to blast events are due to secondary penetrating injuries. Fragments can include parts of the blast device casing itself, materials from surrounding structures, and even pieces of the vehicle in which the victim was an occupant.

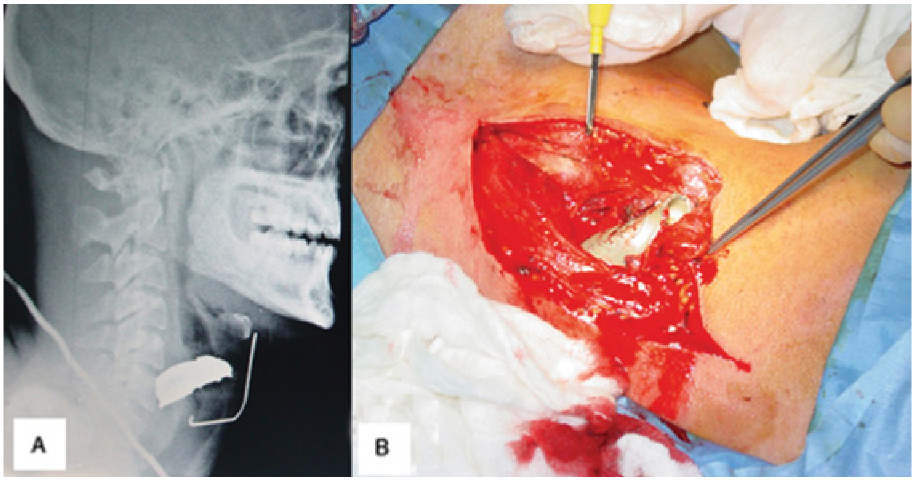


Figure 11.22 A,B IED injuries. Radiological appearance of a fragment in the neck following an IED injury (A). Intraoperative appearance of an IED lodged into the neck (B).

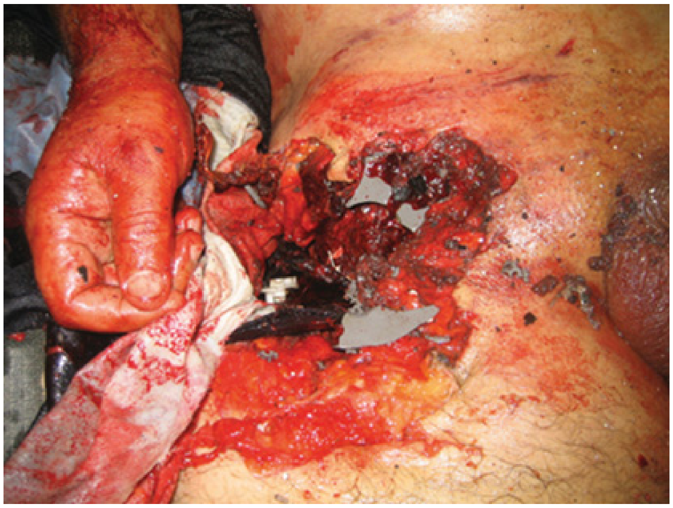


Figure 11.23 Fragments from IED became deeply embedded into a groin wound.

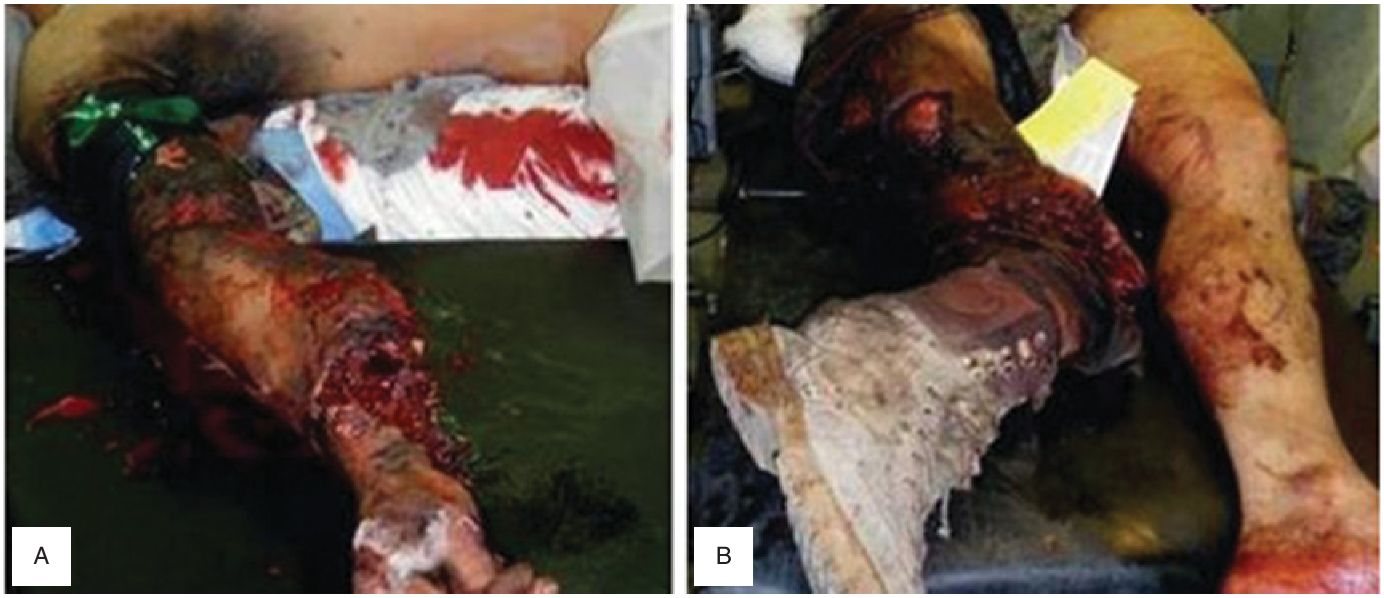


Figure 11.24 A,B IEDs cause the majority of extremity injuries in current conflicts. These are characterized by massive soft tissue and fractures in association with extensive embedded fragmentation and debris. Most of these injuries require amputations.

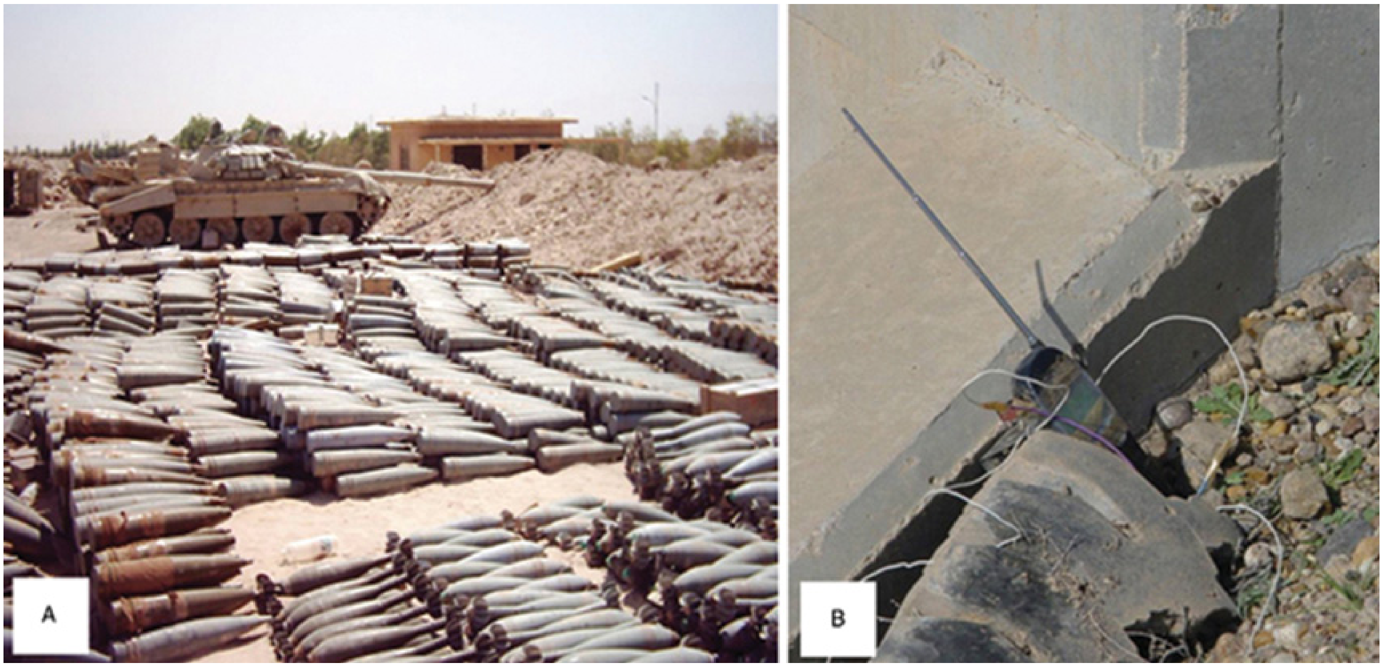


Figure 11.25 **A,B**. Unexploded ordnance is readily available in combat zones from multiple previous conflicts and is commonly used in IEDs (A). As commonly seen, a rudimentary cellular phone is used as part of a remote triggering mechanism (B).

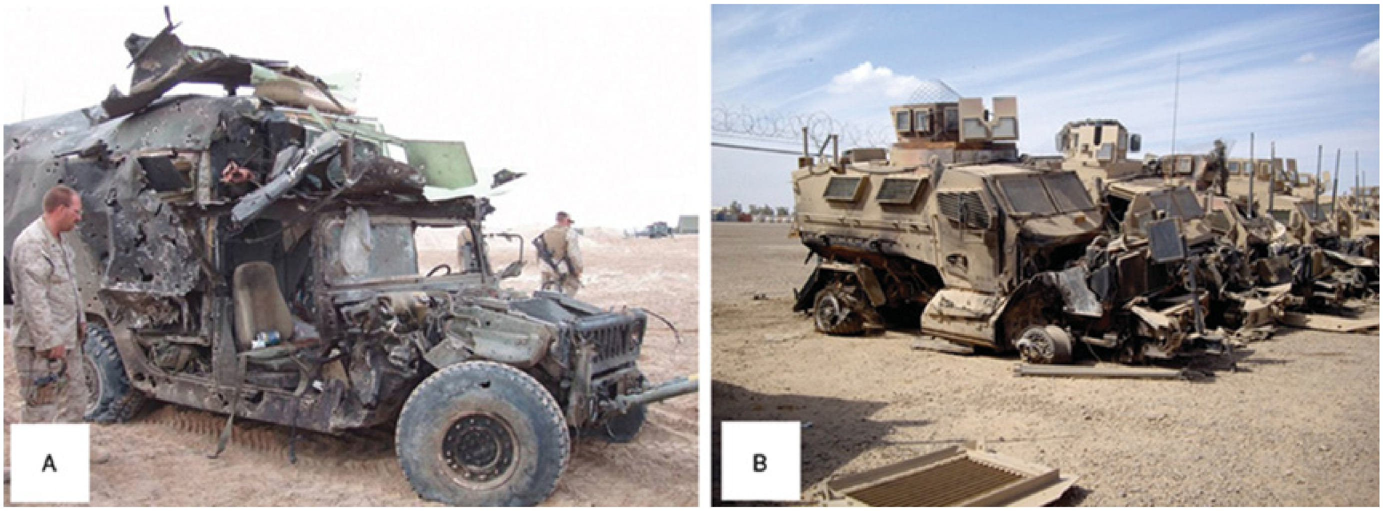


Figure 11.26 A,B IED injuries. Occupants of unarmored vehicles, such as this military ambulance, are essentially defenseless against the effects of a roadside IED (A). In "Mine Resistant Ambush Protected" (MRAP) vehicles, the passenger compartments remain relatively intact due to up-armoring and the blast-deflecting V-shaped undercarriage (B). Significant injuries from blunt trauma can still occur due to violent displacement of the occupants within the passenger compartments.

Nonlethal Weapons

Nonlethal weapons are designed to temporarily incapacitate an individual and are commonly used by police forces. These can include beanbag rounds, rubber bullets, and electroshock discharges (Taser or stun gun). Although much less likely to be lethal than conventional weapons, they can still cause a variety of injuries, including contusions, lacerations, eye injuries, fractures, and internal injury, depending on the location of impact and the proximity to the weapon when it is fired (Figure 11.27, Figure 11.28 A,B).

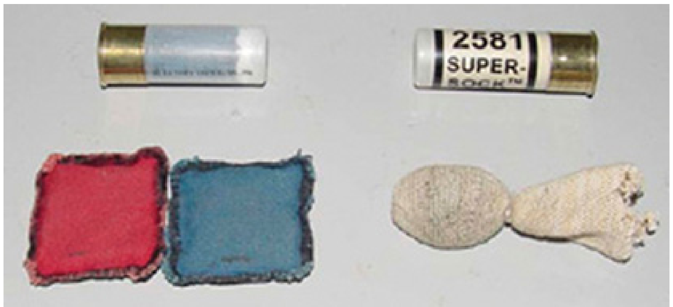


Figure 11.27 Examples of beanbag shells.

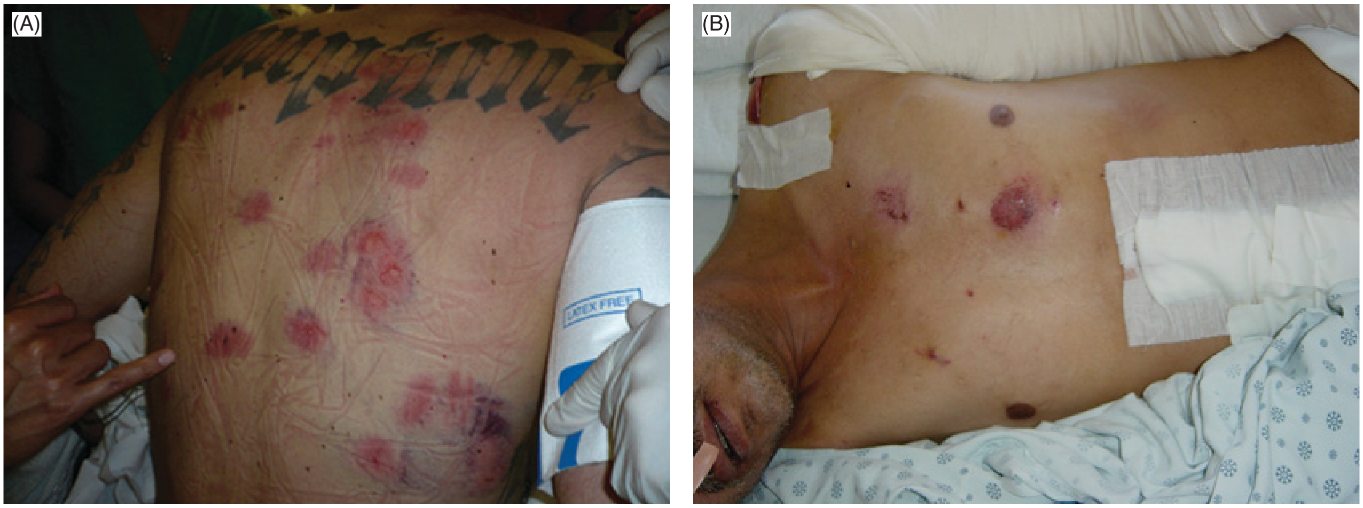


Figure 11.28 A,B Contusions on upper and mid-back and anterior chest after patient was shot with numerous times with beanbag missiles. At close range, these injuries can cause serious injury or even death.

Conductive energy devices (CED), such as the Taser or stun gun, are battery-operated hand-held units, commercially available for both law enforcement and civilian use. The most widely used device in the United States is the Taser. It fires 4 mm darts attached by insulated wires up to 35 ft away. The CED works by discharging electrical bursts causing neuromuscular incapacitation (Figure 11.29 A,B). Although in healthy volunteers no significant complications have been seen, there are case reports of deaths, especially in subjects with associated medical problems or illicit drug intoxication.

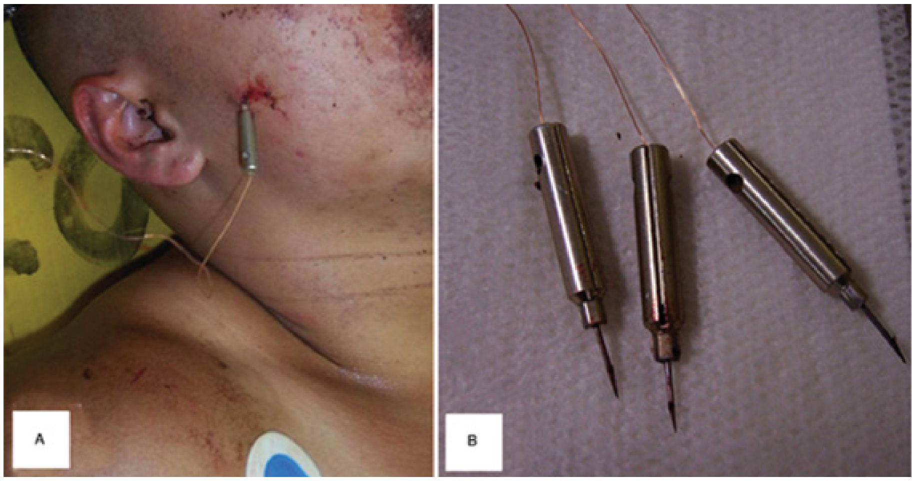


Figure 11.29 A,B Taser injuries. Patient after being subdued by the police using a Taser (A). Note embedded hook in right cheek. Taser hooks removed from the same subject (B).

Myths and Facts about Bullets

There are many inaccuracies and myths regarding bullet properties and the care of bullet injuries.

(a) Myth: High-velocity bullets travel with continuous tumbling. Fact: Most bullets travel straight. Some bullets (AK-47, M-16) flip once (180 degrees) when they hit the tissues and then travel backward.

(b) Myth: Bullets are sterile. Fact: Bullets are not sterile. The high temperature at the muzzle does not last long enough to sterilize the bullet.

(c) Myth: The tissue damage is proportional to the bullet velocity. Fact: The degree of tissue damage depends on the amount of energy released by the bullet. In many cases, the bullet releases only a small amount of energy and exits the body without any major damage.

(d) Myth: Military bullets are made to inflict maximum damage. Fact: Military bullets are jacketed and designed not to fragment or deform on impact. Fragmentation and deformation are critical factors for extensive tissue damage.

(e) Myth: The appearance of the soft tissue injury can reliably distinguish between low-velocity and high-velocity bullets. Fact: In many cases, even ballistic experts cannot reliably distinguish between low- and high-velocity injuries.

(f) Myth: All high-velocity injuries need extensive surgical debridement. Fact: A conservative debridement is more appropriate. Treat the injury, not the velocity.

Chapter

12

Trauma in Pregnancy

Alessandra Conforto and Elizabeth R. Benjamin

Introduction

The pregnant patient represents a double resuscitation, as there are two patients to simultaneously consider. Fetal resuscitation is dependent upon adequate maternal resuscitation and stability and ongoing monitoring of both patients is essential for optimal outcomes. The pregnant trauma patient poses additional challenges because the anatomy and physiology are different from the nonpregnant patient, and this affects the physical exam, the clinical presentation, and the management of the patient.

All women of childbearing age should be considered pregnant until proven otherwise. A urine or serum pregnancy test should be obtained as soon as is feasible on all female patients of childbearing age in the setting of trauma, as self-reporting of the gravid state is notoriously untrustworthy.

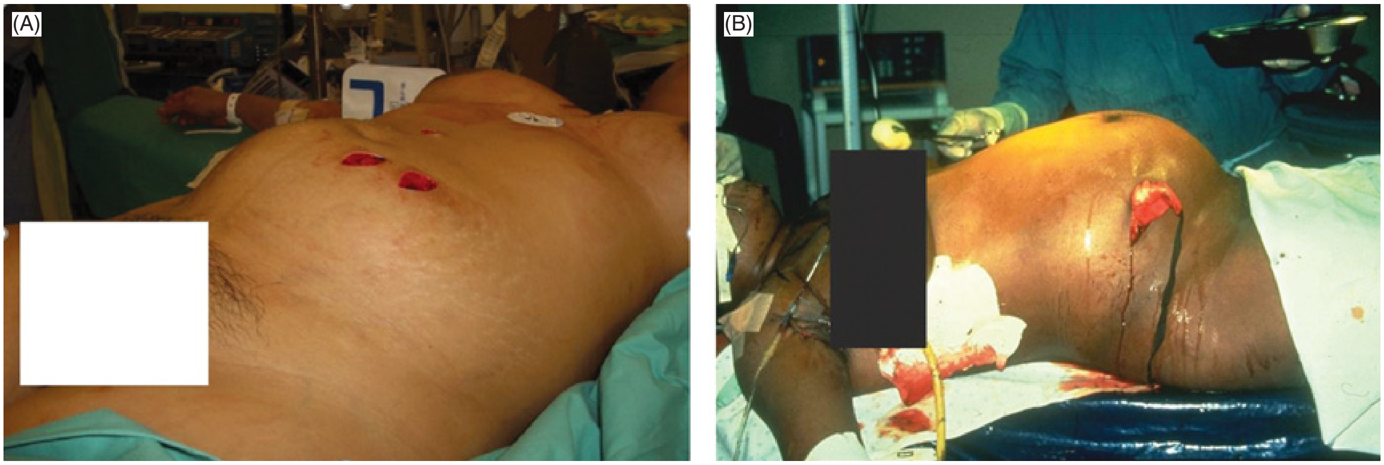
Identifying the viable pregnancy early in the trauma resuscitation (i.e., level of the uterus fundus or fetal ultrasound) is essential to providing adequate care to both the fetus and the mother. Under 22 weeks of gestational age, the pregnancy is deemed nonviable, and resuscitative efforts of the fetus are futile and should be withheld. A gestational age greater than 26 weeks is associated with a high likelihood of survival. The timeframe in between these two dates is associated with variable chance of survival and management is adjusted accordingly. As a general rule, if the fundus of the uterus is two to three fingerbreadths above the umbilicus, the fetus is viable.

Trauma in pregnancy is associated with increased morbidity and mortality for both the fetus and the mother. Even after fairly minor trauma, there is significant risk of placental abruption, uterine rupture, and maternal or fetal death. A multidisciplinary approach including emergency medicine, trauma surgery, obstetrics, and neonatology will ensure the best outcome.

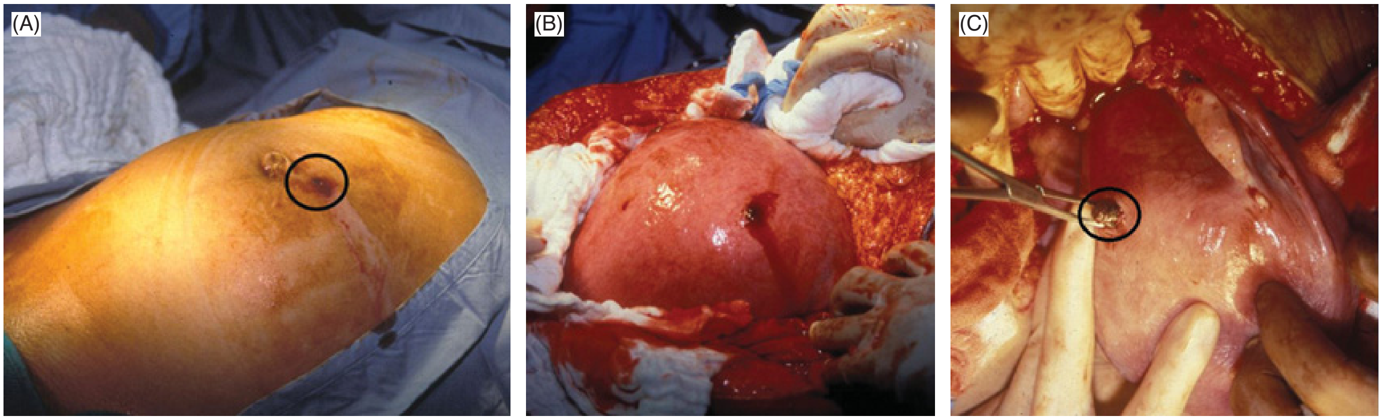
Epidemiology

Trauma is common during pregnancy, affecting one in 12 pregnancies, and trauma is the leading nonobstetric cause of death in pregnant patients, responsible for approximately 46% of all maternal deaths.

The most common causes of traumatic injuries in pregnant women are motor vehicle collisions, domestic violence, assault, and falls. Education regarding proper positioning of the seat belt over the gravid uterus may reduce the incidence and severity of motor vehicle-related trauma, and violence awareness and screening programs are integral to the awareness and prevention of domestic abuse (Figures 12.1 A–B, Figures 12.2 A–C).



Figures 12.1 A–B Intentional trauma in pregnancy is common in many societies. Pregnant patients with knife wounds to the abdomen.



Figures 12.2 A–C Pregnant patient with a gunshot wound to the abdomen (A). Emergency laparotomy revealed a through and through, wound to uterus (B, C). In this situation, if the fetus is viable by gestational age, a cesarian section should be performed.

Blunt trauma, even in the absence of significant maternal abdominal injuries, can result in placental disruption and fetal loss. In addition to acute findings, trauma to the pregnant patient can result in premature labor and low birth weight delivery and victims of domestic violence can have repeat events. For these reasons, in the setting of traumatic injury, pregnancies should be closely monitored even after discharge.

Anatomical Changes of Pregnancy

The uterus is completely protected within the pelvic ring during the first 12 weeks of gestation. As the pregnancy progresses, the uterus grows within the abdominal cavity and becomes more vulnerable to blunt and penetrating trauma. An important landmark is the uterine fundus is palpable at the umbilicus at approximately 20 weeks of gestational age (Figure 12.3). In advanced pregnancy, the uterus displaces the intestine cephalad and laterally, resulting in different injury patterns and altered clinical examination (Figure 12.4). The enlarging uterus compresses the inferior vena cava (IVC), reducing venous return and cardiac output (Figure 12.5). This, in turn, increases bleeding from injuries to the lower extremities. Compression of the IVC may be relieved by positioning the patient in the left lateral decubitus position. This may increase cardiac output by up to 30%. Other anatomical changes in advanced pregnancy include elevation of the diaphragms, which increase the risk of diaphragmatic injury in penetrating chest injuries and reduce the functional residual capacity (Figure 12.3, Figure 12.4, Figure 12.5).

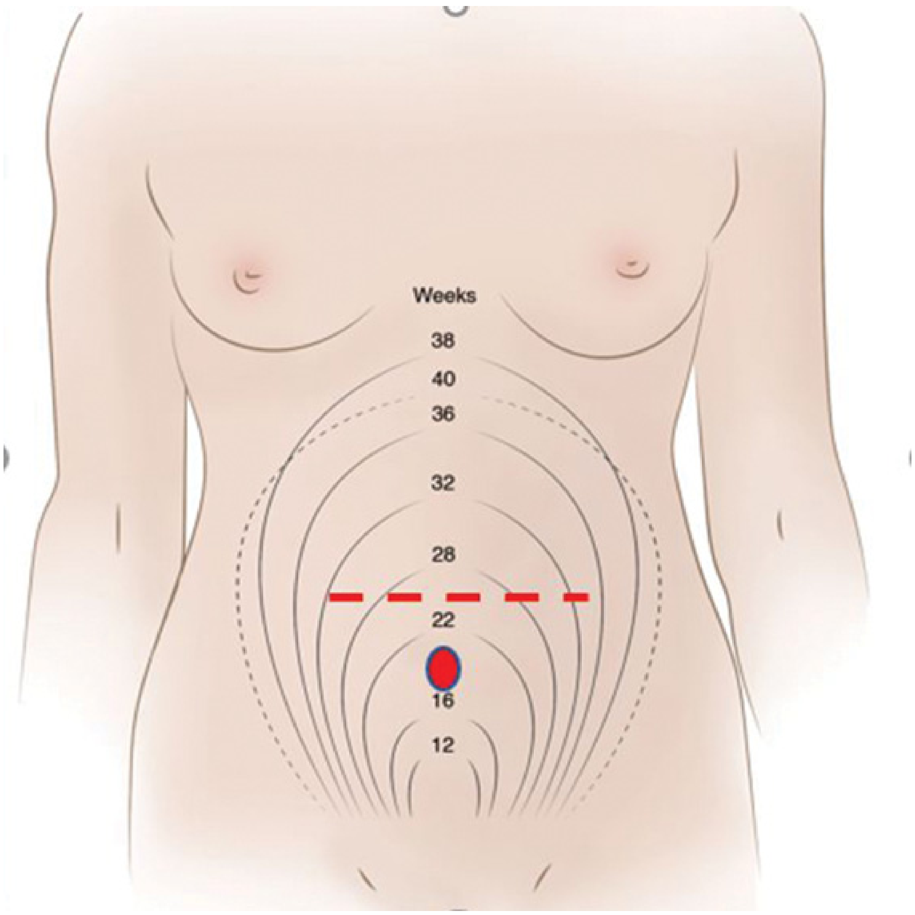


Figure 12.3 At approximately 20 weeks, the uterine fundus can be palpated at the level of the umbilicus (red circle). The fetus is considered potentially viable when the uterus is palpable approximately 3 cm above the umbilicus (dotted red line).

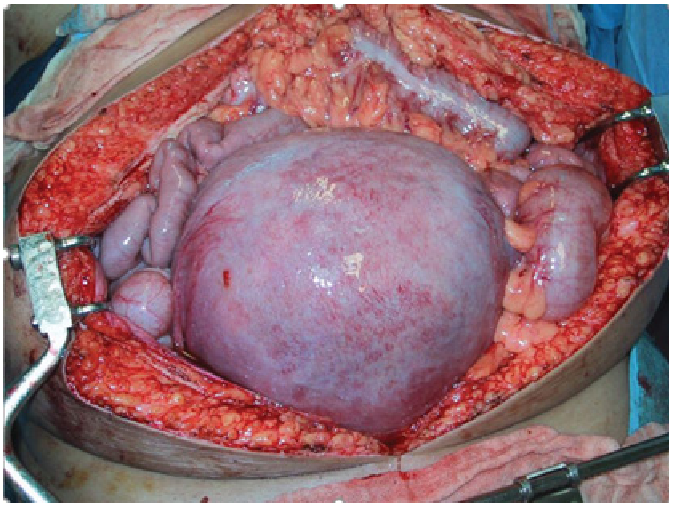


Figure 12.4 As the uterus enlarges, intra-abdominal contents are displaced laterally and superiorly, causing changes in both physiology and clinical examination findings.

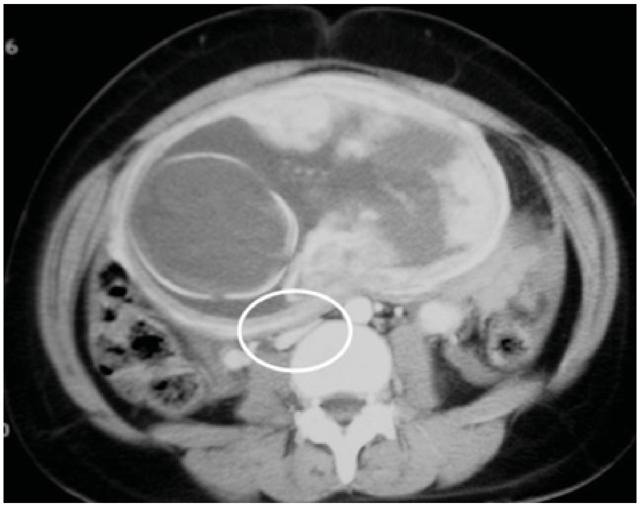


Figure 12.5 The gravid uterus compresses on the IVC when the mother is in the supine position. This can lead to decreased venous return and hypotension, exacerbated by blood loss. Left lateral decubitus positioning may improve compressive symptoms. Also visualized in this CT image is the lateral displacement of the colon by the gravid uterus.

Physiological Changes in Pregnancy

During pregnancy the respiratory system undergoes some changes, including an increased respiratory rate and decreased functional residual capacity, resulting in a mild respiratory alkalosis. Additionally, there is an increase in circulating blood volume with relative anemia preparing the maternal body for a significant blood loss at time of delivery. Blood pressure drops slightly during the second trimester, and the heart rate typically increases. Significant blood loss of up to 1,500–2,000 ml can occur before hypotension is measured. During blood loss, there is autotransfusion from the placenta to the mother, stabilizing the maternal hemodynamics but resulting in fetal hypoxia. Fetal oxygenation is maintained if maternal PaO_2 is above 60–70 mmHg and is compromised below that level, resulting in fetal distress. For this reason, the best resuscitation for the fetus is the resuscitation of the mother.

Trauma Resuscitation

The basic principles of ATLS should be applied, having in mind the special anatomic and physiologic differences in pregnancy. The resuscitation team should include obstetrics and neonatology in all cases with a potentially viable fetus. Resuscitative efforts are guided by the needs of the mother, and maternal outcome is the strongest predictor of good fetal outcome.

The pregnant patient with a uterine fundus palpable at the umbilicus should immediately be placed in 25–30 degrees of left lateral decubitus, either by tilting the backboard if in spinal precautions or by placing rolled-up towels behind the patient's right flank once the backboard has been removed. All patients should receive supplemental oxygen, irrespective of SaO2.

If a thoracostomy tube is required, it should be placed one to two intercostal spaces higher than the usual fourth to fifth intercostal space recommended for nonpregnant patients, due to the diaphragmatic elevation that occurs during pregnancy with increased abdominal contents.

If immediate blood transfusion is necessary before type-specific or cross-matched blood is available, O negative blood is the blood product of choice in order to avoid potential Rh sensitization of an Rh-negative mother. Massive transfusion protocol (MTP) should be initiated as needed. Vasopressors can further jeopardize placental perfusion due to their vasoconstrictor effect and should be avoided.

The abdominal and pelvic examination should include the level of the fundus of the uterus in order to estimate gestation. Abdominal tenderness to palpation or uterine tetany may be seen in placental abruption and fetal parts presenting through a ruptured uterine wall may be palpable as irregularities of the abdominal wall, mandating immediate surgical intervention. The presence of blood in the abdominal cavity does not always present as peritonitis, as signs of peritoneal irritation are muted in pregnancy. The presence of vaginal bleeding may be due to placenta abruption or vaginal tear, especially in patients with pelvic fractures. If there is significant bleeding, a digital exam with sterile gloves and speculum inspection is performed to determine the source of bleeding. Caution is taken to avoid accidental injury to the placenta and exacerbation of bleeding through a partially dilated cervix. If there is minimal bleeding, the vaginal exam may be deferred until placenta previa has been ruled out by ultrasound. In the absence of vaginal bleeding, the pelvic examination should be performed to evaluate for the pooling of amniotic fluid and to evaluate the presence and stage of active labor (cervical dilatation, effacement, and fetal station).

Investigations

Laboratory Testing

A complete blood count (CBC), chemistry panel, liver function tests, and lipase, as well as coagulation studies and urinalysis, are commonly monitored in the setting of major trauma. Obtaining a baseline serum fibrinogen and monitoring over time can be useful in the pregnant patient. It is important to determine the patient's blood type not only to provide cross-matched blood if needed but also to determine the Rh status of the mother. If the patient is Rh-negative, anti D Immune globulin G (RhoGam) should be administered within 72 hours of the exposure. One vial of 300 mg of immune globulin usually provides adequate protection. The Kleinhauer-Betke (KB) test quantifies the amount of fetal blood in the maternal circulation that occurs in the setting of maternal fetal hemorrhage (MFH) and is typically used to determine the need for recurrent immune globulin dosing.

Imaging Studies

Plain radiography and CT scans should be ordered as clinically indicated. It is estimated that the unshielded fetus receives approximately 30% of the radiation dose to which the mother is exposed, and the magnitude of the harm depends on the dose and gestational age. The risk of harm to the fetus from radiation exposure is highest during organogenesis (weeks 8 to 15), then decreases progressively throughout the duration of the pregnancy. The effects of radiation on the developing fetus range from fetal loss to organ malformation, neuro-behavioral issues, and future carcinogenesis. Risk to the fetus is highest in the setting of recurrent CT scans or high radiation procedures, such as fluoroscopy for pelvic or liver angioembolization.

Whenever possible, the risks and benefits of radiation exposure should be discussed with the patient or family. However, in life-threatening situations, the risk of radiation exposure should not influence diagnostic studies or overall care. Ultrasound and MRI are preferable to CT scan, if they can provide the information needed in a reliable and timely manner.

Ultrasound

A FAST examination should be performed early during the primary survey. During this initial bedside sonographic examination, it is essential to estimate the gestational age of the pregnancy and the presence of fetal heart tones. Determining the gestational age of the pregnancy will guide the subsequent steps of the resuscitation. A fetal heart rate of 140–160 indicates fetal well-being.

Once the patient has been stabilized, a formal obstetric ultrasound is recommended. This study provides accurate estimation of gestational age, detailed information about the fetus, quantity of amniotic fluid, and position of the placenta. A formal ultrasound is not reliable in excluding placental abruption, the most concerning obstetrical complication after trauma, and a normal exam should not provide false reassurance (Figure 12.6, Figure 12.7, Figure 12.8, Figure 12.9).

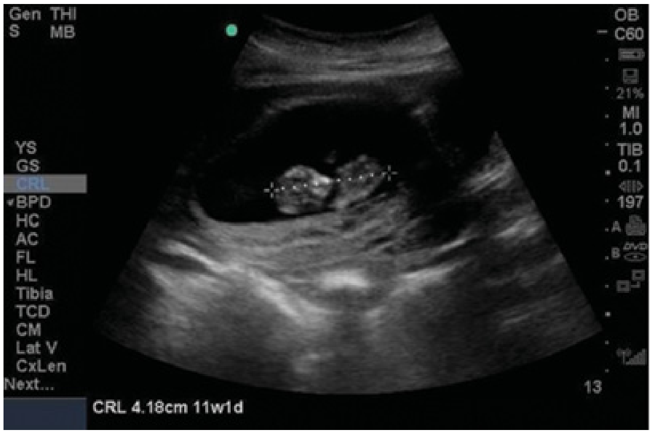


Figure 12.6 The crown-rump length (CRL) is typically the most accurate measurement of gestational age during weeks 6–13 of pregnancy). (Image courtesy of Dana Sajed, MD).

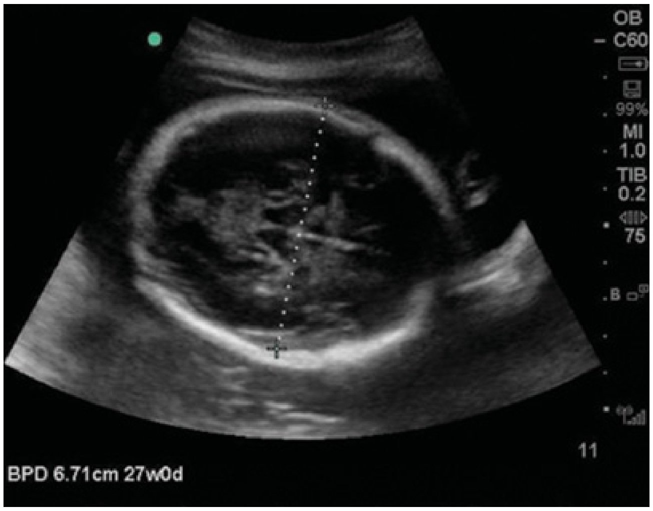


Figure 12.7 The biparietal diameter (BPD) is frequently used to evaluate gestational age from the second trimester forward. (Image courtesy of Dana Sajed, MD).

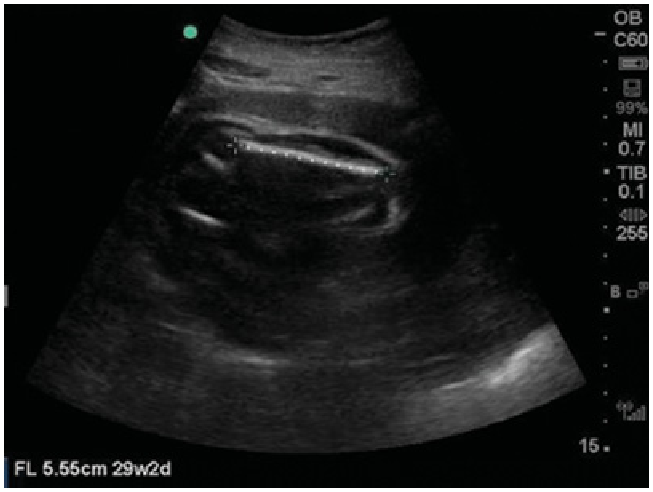


Figure 12.8 Femur length (FL) is another biometric parameter that may be used in the second or third trimester to estimate gestational age. (Image courtesy of Dana Sajed, MD).

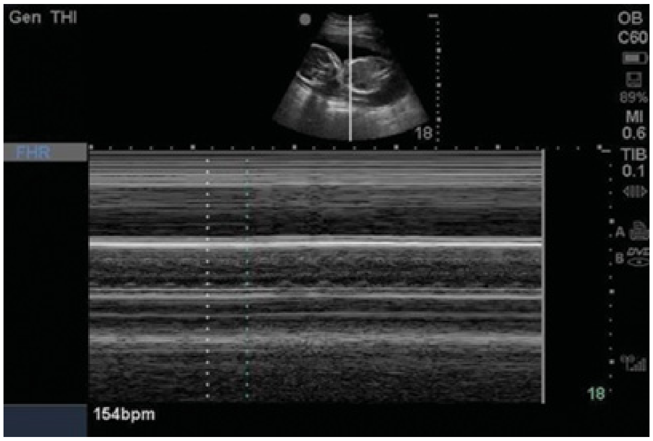


Figure 12.9 Calculation of fetal heart rate (FHR). Using the M-mode function, a line is placed on the screen. The line should be placed over the beating heart, after which M-mode is pressed again. The resulting image represents movement seen through the M-mode line. Generally one is able to see a sinusoidal wave across the screen, which shows movement of the beating heart. Calipers should then be placed from peak-to-peak (alternatively, from valley-to-valley), and an automated calculation of heart rate can then be made. A normal FHR usually ranges from about 140 to 160 beats per minute (bpm). (Courtesy of Dana Sajed, MD).

Electronic Fetal Monitoring (EFM)

EFM should be initiated as soon as is feasible upon recognition of a viable fetus (≥23 weeks). The purpose of maternal-fetal monitoring is the early detection of obstetrical complications before fetal compromise ensues. It consists of continuous monitoring of both fetal heart rate and maternal uterine contraction. Alone, it is not reliable in predicting adverse fetal outcome; however, in the setting of a normal physical exam, a normal tracing has a high negative predictive value in excluding major adverse fetal event. Monitoring should continue at least four to six hours after minor trauma and with a normal physical exam. Longer monitoring and observation is recommended in the setting of symptoms including uterine tenderness, significant abdominal pain, vaginal bleeding, frequent uterine contractions, rupture of membranes, abnormal fetal heart rate pattern, elevated serum fibrinogen, and high-risk mechanism (Figure 12.10).

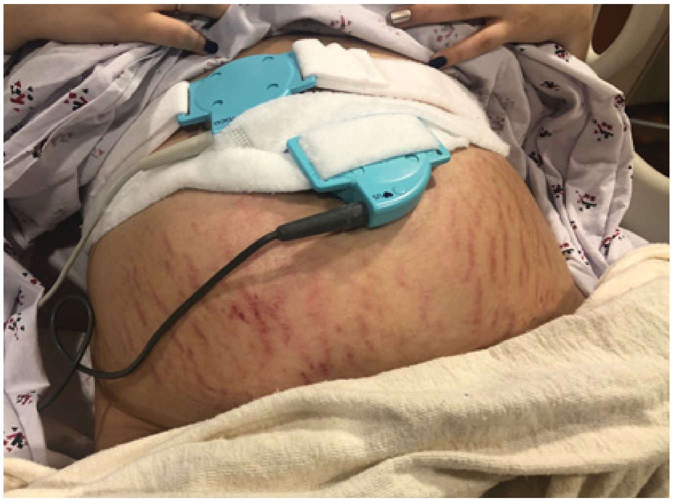


Figure 12.10 Patients with potentially viable pregnancies should undergo continuous fetal heart rate and uterine contraction monitoring for a minimum of four to six hours post trauma.

Common abnormalities in fetal heart rate are decelerations, bradycardia, tachycardia, and loss of beat-to-beat variability. These indicate the need for further maternal and fetal resuscitation. Fetal distress is defined as a fetal heart rate <90, and in a viable fetus, this is a strong indication for an emergency C-section.

Uterine Contractions

Placental abruption should be suspected in the setting of elevated basal uterine tone. Uterine contractions are common in the setting of trauma and tend to resolve within four to six hours in the vast majority of cases. Persistent uterine contractions that do not resolve with rest, fluids, and supplemental oxygen are concerning for placental abruption.

Obstetrical Complications

Fetomaternal Bleeding

In Rhesus-negative mothers and Rhesus-positive embryos, fetomaternal bleeding may cause erythroblastosis fetalis in future pregnancies. Immunoglobulin (Rho- Gam) should be administered as described.

Placental Abruption

Placental abruption is a common dreaded complication, and may occur even after minor trauma. In this complication, the placenta shears off the myometrium, resulting in bleeding. This can lead to exsanguination, coagulopathy, and fetal or maternal death. Placental abruption is the leading cause of fetal death secondary to trauma and is responsible for 50–70% of trauma-related fetal deaths. The abruption can be central and usually presents with pain and signs of blood loss without significant vaginal bleeding. A peripheral abruption might not be painful but may present with significant vaginal bleeding. It typically manifests within 24 hours of the trauma, the majority of cases presenting within 4–6 hours. The diagnosis of abruption is most commonly supported by abnormal maternal-fetal tracings. Ultrasound is insufficient to reliably rule out placental abruption, and CT scan is often performed for additional evaluation. In the setting of potential abruption, maternal coagulation parameters should be closely monitored, as disseminated intravascular coagulation (DIC) is a known complication.

If signs of fetal distress are present, and the fetus is viable, the treatment for abruption is C-section delivery. Early intervention is associated with good outcomes and survival rates of up to 75%.

Uterine Rupture

Uterine rupture is a rare complication that generally occurs with direct trauma to the uterus in the final stages of pregnancy, particularly when the integrity of the uterus has been weakened by previous scarring. It usually involves the fundus.

Symptoms suggestive of uterine rupture include abdominal pain with signs of peritonitis and often, severe hypotension. An irregular uterine contour and palpable fetal parts are also highly suspicious of uterine rupture. This is a life-threatening injury for both the mother and the fetus. The fetal mortality is nearly 100%. Treatment consists of emergent laparotomy with hemorrhage control.

Amniotic Fluid Embolization

Amniotic fluid embolus is a fairly rare but highly lethal complication with a maternal mortality of up to 80%. It is usually complicated by acute respiratory distress syndrome and DIC.

Indications for Emergency Cesarian Section

Cesarean section should be considered in the following conditions:

- Fetal distress, if the fetus is viable (>23 weeks) (Figure 12.11)
- Maternal death or imminent death, if the fetus is viable
- Selected cases with major maternal complications (severe bleeding, eclampsia, DIC, amniotic fluid embolization)
- During laparotomy, if the exploration and management of maternal injuries are difficult due to the presence of the enlarged uterus

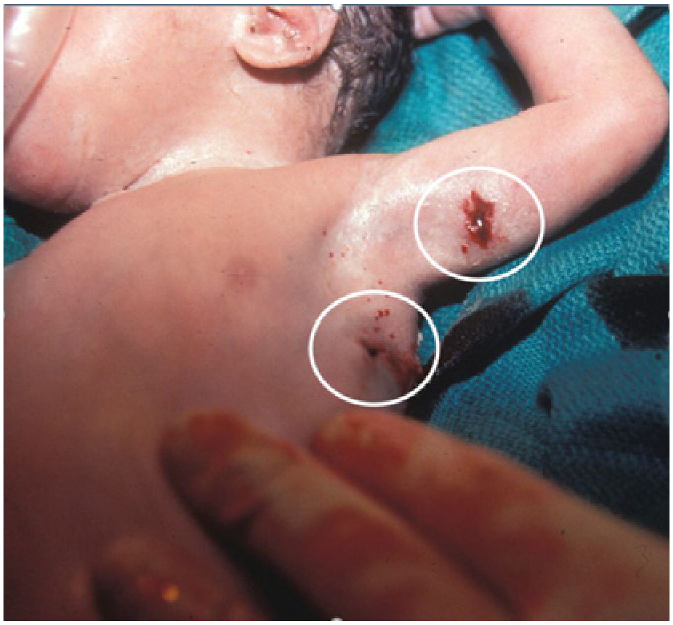


Figure 12.11 Newborn delivered via emergency Cesarian section after the mother sustained a GSW to the abdomen, through the uterus with fetal left arm and thoracoabdominal injuries. Both mother and fetus survived.

Peri-Mortem Cesarian Section

This desperate procedure should be performed at the location of cardiac arrest, in cases of maternal death or imminent death, if the fetus is potentially viable (Figure 12.12). Obstetrics and neonatology should be part of the resuscitation team. The best results are achieved if the fetus is delivered within 5 minutes of maternal death. Fetal survival with Cesarean section 15–20 minutes after maternal death has been reported, although the incidence of hypoxic brain damage is high. In addition to the possibility of fetal salvage, the Cesarian section improves the chances of maternal cardiopulmonary resuscitation, by decompressing the IVC and removing any source of bleeding from the placenta or the uterus above the umbilicus (Figure 12.12).

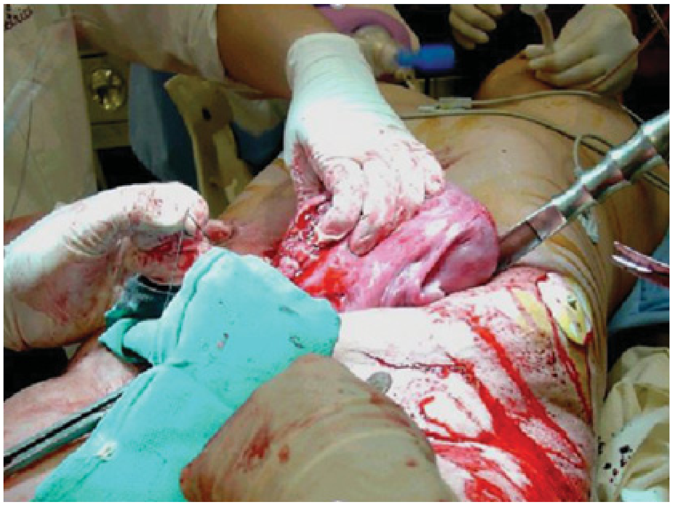


Figure 12.12 Emergency room Cesarian section performed after trauma.

Tips and Pitfalls

- All female trauma patients of childbearing age should be evaluated for pregnancy.
- The best resuscitation of the fetus is adequate resuscitation of the mother!
- Place the patient with advanced pregnancy (palpable uterine fundus at the umbilicus) in 20–30 degrees right side up, to relieve compression on the IVC.
- Even minor trauma is associated with fetal complications, especially placenta abruption. Maternal and fetal monitoring should be performed liberally.
- In advanced pregnancy the patient might be hemodynamically “stable,” even after the loss of 1,500–2,000 ml, because of autotransfusion from the placenta.
- Administer routinely supplemental oxygen, even if the maternal SaO2 seems normal.
- In advanced pregnancy, a thoracostomy tube should be placed one or two intercostal spaces higher than usual, because of the elevated diaphragm.
- An emergency Cesarian section may be life-saving for the fetus and improves the resuscitation efforts of the mother.

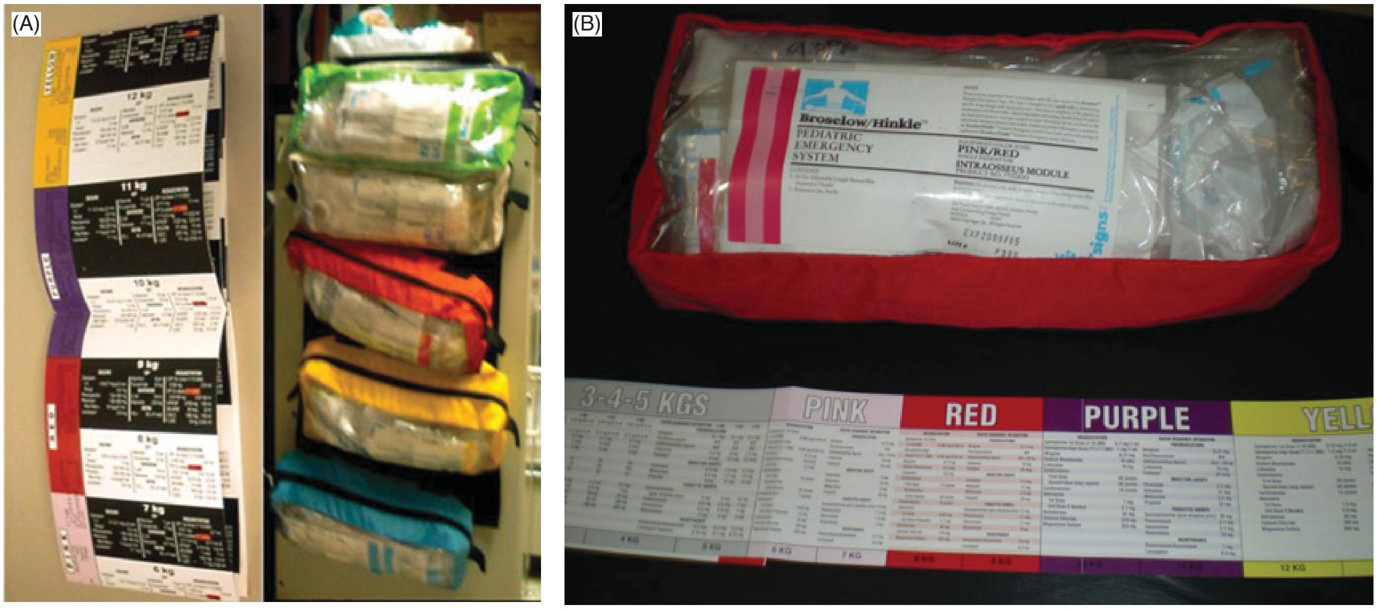


Figure 13.2 A,B Pediatric Broselow tape and color-coded packs containing age-appropriate airway and resuscitation instruments and catheters.

Airway

- Infants are nose breathers. Keep nares clear; use an orogastric tube rather than a nasogastric tube.
- Children have a larger tongue and larger adenoids relative to the size of their oropharynx. The use of an oropharyngeal airway device should be considered as needed.
- The epiglottis in pediatric patients is a narrow, floppy, and curved structure; thus the use of a straight Miller blade as opposed to a Macintosh (i.e., MAC) blade is preferred to help lift the epiglottis and expose the glottic opening.
- The vocal cords are higher and more anterior than in adults.
- Traditionally, an uncuffed endotracheal tube was recommended for pediatric patients; however, with new technology tubes, this is a recommendation no longer deemed necessary.
- The pediatric trachea is shorter in length relative to the adult, and therefore there is an increased risk of right mainstem intubation or inadvertent tube dislodgement. Inserting the tube to a length three times (in cm), the endotracheal tube size can help prevent this complication (Figure 13.3).
- Cricothyroidotomy should be avoided in children <6 years of age because of the high incidence of tracheal stenosis. In situations of inability to oxygenate or ventilate, a needle cricothyrotomy with jet ventilation is performed as opposed to a surgical cricothyrotomy.

Breathing

- In pediatric patients, the respiratory rate is age-dependent. Children have less chest wall musculature and are more reliant on their diaphragm. This puts children at risk of becoming fatigued more quickly than adults, and a decreasing respiratory rate may be indicative of impending respiratory failure.

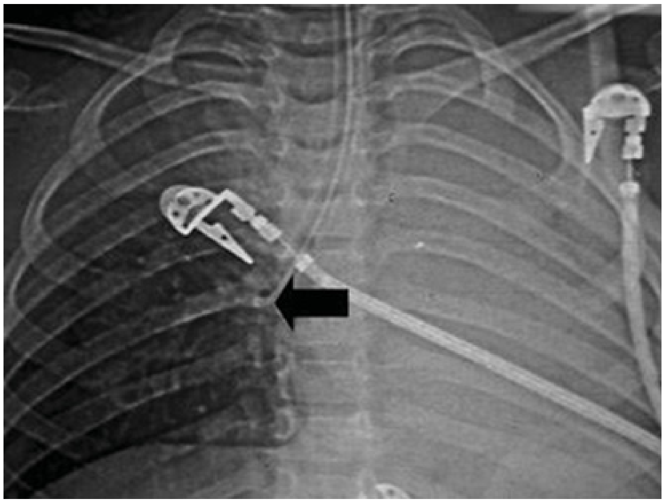


Figure 13.3 Right mainstem intubation, with no ventilation of the left lung.

- For children who are not maintaining adequate ventilation, bag mask ventilation can provide temporary respiratory support. It is important to ensure that proper size and methods are used to reduce the risk of barotrauma. Most pediatric bag valve mask systems are now equipped with a “pop-off” valve to limit maximal pressure to 35–40 cm H_2O; however, adequate chest rise should be assessed with each breath (Figure 13.4).
- Children have a smaller functional residual capacity and can quickly desaturate during intubation. Maximizing preoxygenation and using apneic oxygenation can help mitigate the risk of hypoxia.

- Children with normal mental status, no focal neurologic deficits, and no physical evidence of skull fracture are classified as having a minor head injury. Only 5% of children presenting to the emergency department with a minor head injury have an intracranial injury, and <1% of those patients require neurosurgical intervention.
- The Pediatric Emergency Care Applied Research Network (PECARN) clinical prediction rule for children is used to determine if a child is at very low risk of a clinically important intracranial injury and therefore can forgo CT scan imaging. This decision tool is divided by age:
  - <2 years old: Normal mental status, no scalp hematoma except frontal, no loss of consciousness, no palpable skull fracture, nonsevere mechanism, and acting normal according to parents; no head CT indicated.
  - ≥2 years old: Normal mental status, no loss of consciousness, no vomiting, nonsevere injury mechanism, no signs of basilar skull fracture, and no severe headache; no heat CT indicated.
- Indications for CT of the head in pediatric patients should include GCS<15, history of loss of consciousness, amnesia, seizures, headache, suspected CSF leak from the nose or ear, raccoon eyes, and Battle's sign. If the only sign or symptom is a scalp hematoma, the child should undergo either a CT scan or observation in the emergency department for about 6 hours.
- Skull X-rays are not routinely performed for blunt head trauma because they do not provide information regarding intracranial injuries, and they often miss skull fractures.
- Children are much more likely to develop EDH than adults because of the loose adherence of the dura mater to the skull (Figure 13.6 A,B, Figure 13.7).

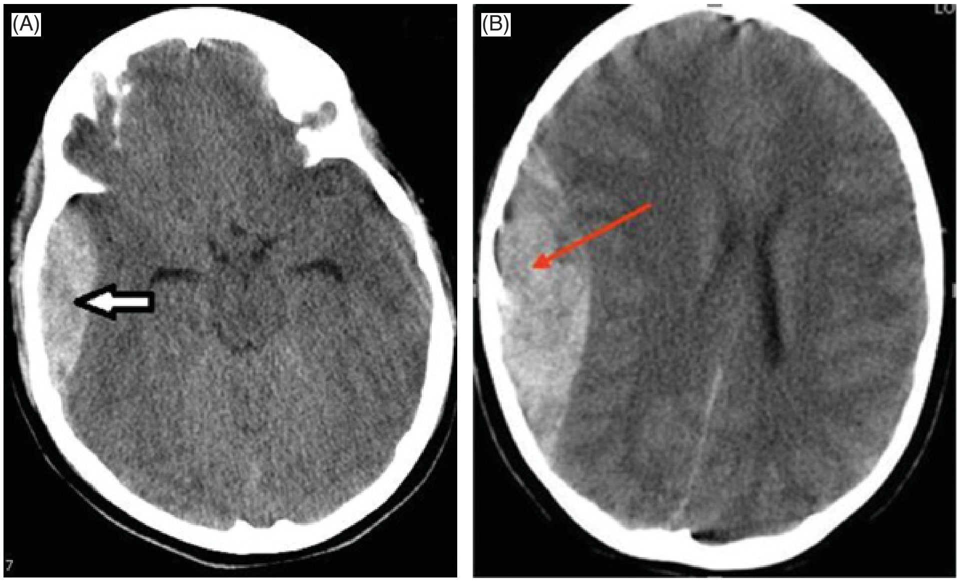


Figure 13.6 A,B A 10-year old child with head trauma, following a bicycle fall. CT scan showing a right temporal epidural hematoma (arrow; A). Pediatric head trauma following auto versus pedestrian injury. CT scan showing a large right EDH (arrow) with midline shift (B). The mixed density of the hematoma is suggestive of active bleeding.

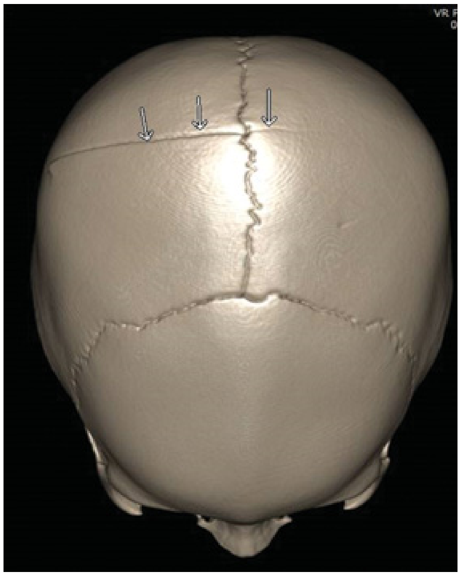


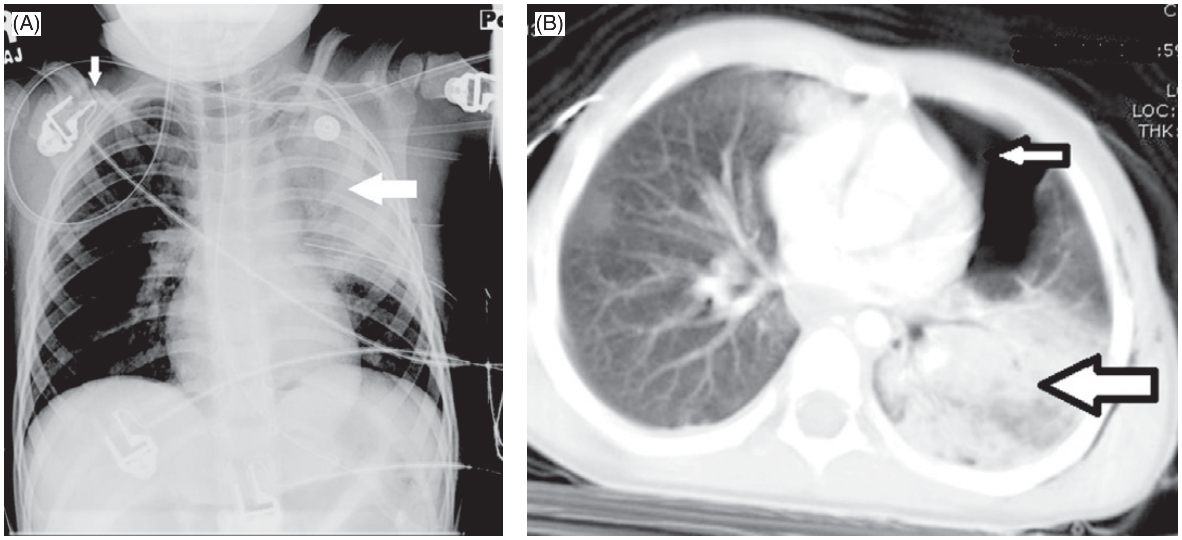
Figure 13.7 A two-year old child after a fall from a height. CT scan showing a linear skull fracture (arrows).

  - Normal wedging of an intervertebral space or the body of C3 may be mistaken for spinal trauma.
  - Normal translucencies of the dens due to incomplete ossification may be mistaken for fracture.

- Spinal cord injury without radiographic abnormality (SCIWORA) is more common in children.
- CT imaging has increased sensitivity and specificity, but its routine use is also controversial due to risk of radiation and increasing the lifetime risk of malignancy.

Thoracic Trauma

Children suffer rib fractures less often than adults. When present, they indicate severe trauma. Pulmonary contusions are more common in children than in adults, and they often occur without rib fractures. Aortic rupture is rare (Figures 13.10 A,B).



Figures 13.10 A,B A four-year-old child with blunt chest trauma. Chest X-ray demonstrating right clavicle fracture (small arrow) and left lung contusion (large arrow; A). Chest CT scan showing a left lung contusion (large arrow) and a left pneumothorax (small arrow; B).

Abdominal Trauma

- Evaluate as in adults.
- Very young children swallow a lot of air and may develop gastric distention. This might interfere with the respiratory function and complicate the abdominal evaluation (Figure 13.11 A,B).

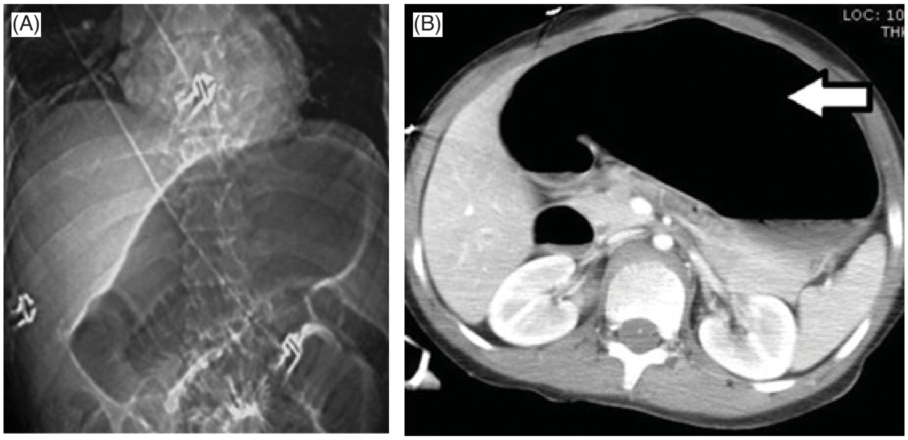


Figure 13.11 A,B Abdominal X-ray and CT scan of the abdomen of an infant trauma patient showing massive gastric distention. This distention might cause respiratory problems and complicate the physical examination of the abdomen.

- Nonoperative management of splenic or liver injuries is more successful in children than adults because of the thick and elastic capsule of these organs, and the ability of the vessels to constrict (Figure 13.12 A,B, Figure 13.13 A,B).

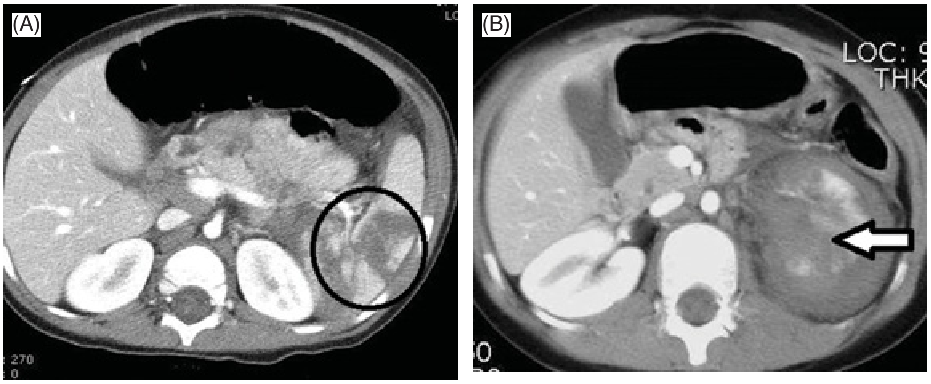


Figure 13.12 A,B Grade IV splenic injury (circle) in a two-year-old child, successfully managed nonoperatively (A). Grade IV left kidney injury (arrow) in a five-year-old child, successfully managed nonoperatively (B).

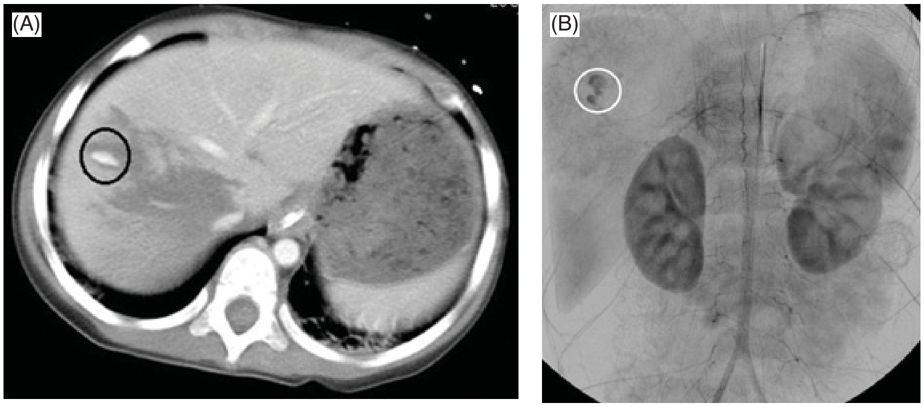


Figure 13.13 A,B Grade IV liver injury in a three-year-old child, with active bleeding (circle; A). Angiography showing active bleeding (circle), which was successfully embolized (B).

Non-accidental Trauma

- The diagnosis of abuse should be considered when there are injuries in different stages of healing or injuries involving multiple body parts. Social factors that are concerning factors for abuse include a history that does not match the injury pattern or developmental stage of the child, delayed presentation, or changing accounts of the event (Figure 13.14).
- Certain fracture patterns should raise concern for non-accidental trauma. These include rib fractures, fractures of the sternum, scapula, or spinous processes, metaphyseal chip fractures, long bone fractures in nonambulatory infants, and fractures in multiple stages of healing. The work-up for fractures includes a skeletal survey. A whole-body X-ray, also known as a "babygram," often is not sufficient, and dedicated views of the axial and appendicular skeleton may be necessary (Figure 13.15 A,B, Figure 13.16 A,B).
- Certain bruises are suspicious for child abuse. The TEN-4 rule (bruising on the torso, ear, or neck [TEN] or bruising on any area in children younger than 4 months of age) may help the physician in suspecting abuse. Recognition of patterned bruises such as belts, handprints, and loop marks are also highly suspicious for abusive injury (Figure 13.17).

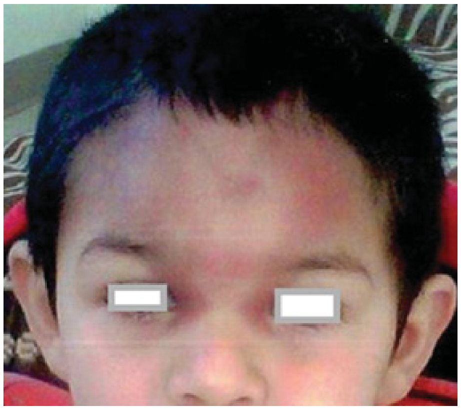


Figure 13.14 Missed child abuse in a two-year-old boy, who presented at a clinic with multiple bruises on the face and the rest of the body. A few months later, the boy died from severe intraabdominal bleeding as a result of abuse by the mother's boyfriend.

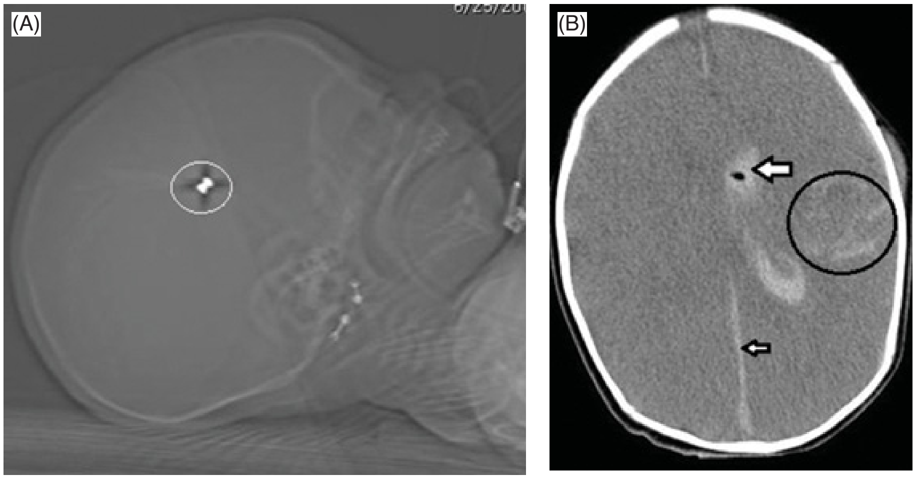


Figure 13.15 A,B A two-month-old baby brought to the emergency room for altered mental status. The emergency physician suspected abuse because of an inconsistent history. Skull X-ray showed a pellet in the brain (circle; A). CT scan showed intraventricular bleeding (large arrow), subarachnoid hemorrhage (circle), and falx subdural hematoma (small arrow; B).

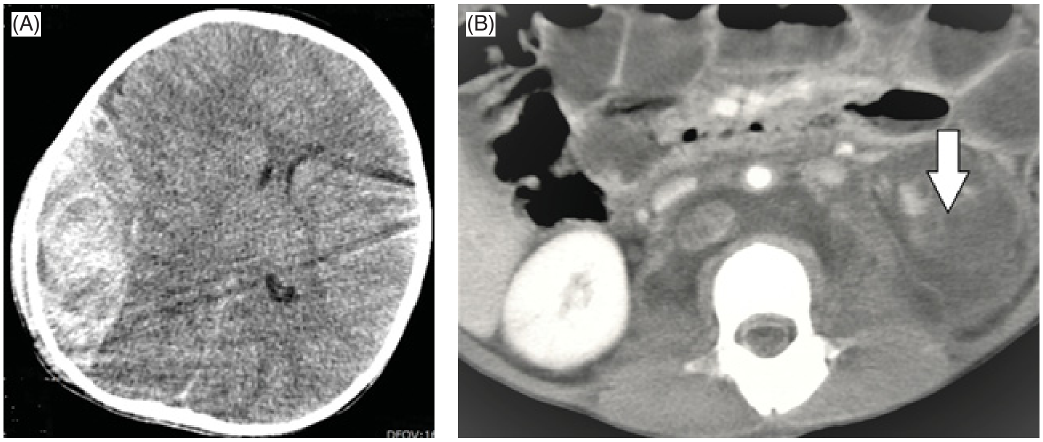


Figure 13.16 A,B A nine-month-old baby admitted in critical condition. The physician suspected abuse. CT scan of the head shows a large right EDH, with mixed densities (black and white areas in the hematoma), suspicious for active hemorrhage or acute on chronic bleeding (A). Contrast CT of the abdomen revealed left renal artery thrombosis with no renal uptake (arrow; B).

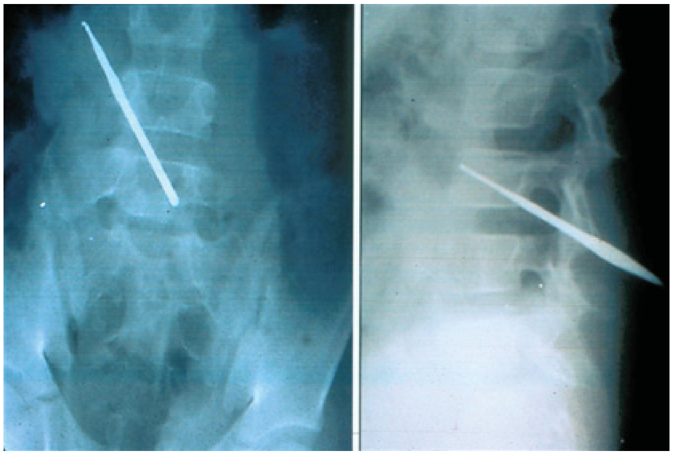


Figure 13.17 Child admitted to the emergency department with suspected signs of abuse. X-ray revealed a needle in the spine.

Tips and Pitfalls

- Pediatric patients maintain "hemodynamic stability," even after significant blood loss due to their increased ability to vasoconstrict. This may create a false sense of security. However, without resuscitation, they often decompensate rapidly, with very little warning!
- Severe gastric dilatation due to swallowing of air may cause respiratory difficulties or complicate the abdominal examination. Insert a decompressive gastric tube in appropriate cases.
- Administration of atropine during rapid sequence intubation may prevent bradycardia.
- Check the position of the endotracheal tube soon after intubation. There is a high incidence of right mainstem intubation in the pediatric population.
- Consider child abuse in suspicious patterns of injury.
- Dosage of emergency medications and selection of catheter sizes may be challenging. Use the Broselow tape and pediatric carts.

Chapter

14

Geriatric Trauma

Elizabeth R. Benjamin and Matthew Wiepking

General Principles

- Blunt trauma, especially due to falls, is the most common mechanism of injury in the elderly population.
- With similar mechanism, the type and severity of injuries differ compared to other adults.
- Geriatric patients have decreased physiologic reserve and an increased incidence of comorbidities. The prognosis is worse than younger patients with similar injuries.
- In elderly trauma patients, the initial vital signs are often misleading, and undertriage is very common. The prehospital triage and trauma team activation criteria should be more liberal than in younger trauma patients.
- Cardiac medications can influence physiologic response, and anticoagulants can exacerbate bleeding complications, especially in head trauma.
- Early trauma team involvement and early intensive monitoring have been shown to improve outcomes in elderly trauma patients.

Presentation and Primary Survey

Always follow ATLS principles, having in mind age-related specific problems.

Airway

- Elderly patients have limited respiratory reserve and often decompensate rapidly and unexpectedly. Liberal, early endotracheal intubation should be considered. Good preoxygenation should be a priority whenever possible.
- Remove any dentures to prevent dislodgement and airway obstruction.
- Degenerative disease, rheumatoid arthritis, or previous surgery may result in limited range of cervical spine motion, and endotracheal intubation may be more challenging (Figure 14.1 A,B).

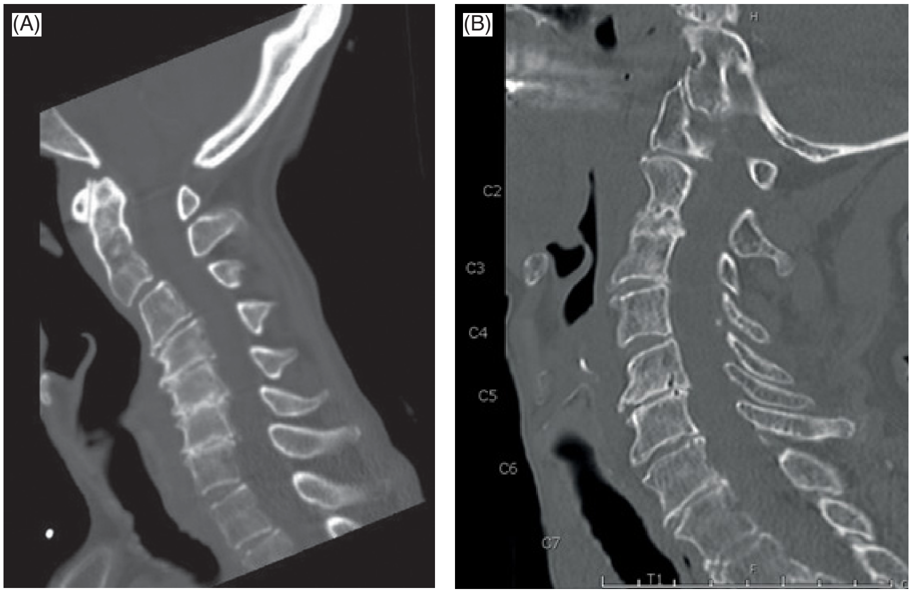


Figure 14.1 A,B Trauma patient, 82-year-old female, with no acute traumatic cervical spine injuries but with kyphotic curvature, degenerative disease, and multilevel disc disease (A). Trauma patient, 89-year-old female, with degenerative disease of the cervical spine (B).

Breathing

- Elderly patients have decreased respiratory reserve. Consideration for early intubation is recommended in the presence of multiple rib fractures or lung contusions, even if the initial oxygenation is normal.

Circulation

- Elderly patients often fail to respond with tachycardia, even after severe trauma, due to atherosclerosis, poor response to endogenous catecholamines, cardiac medications such as beta blockers, and cardiac pacemakers (Figure 14.2 A,B).
- Hypertension is a common comorbidity in geriatric patients and blood pressures that may be considered normal in younger patients may represent hypotension in this population. Hypotension in geriatric patients might be more appropriately defined as a systolic blood pressure of <110 rather than <90 mmHg and heart rate >90 rather than >120 beats/min.
- Many older patients are on diuretics, which result in chronic hypovolemia, thus increasing the risk of cardiovascular collapse, even after modest blood loss.
- Older patients, with reduced left ventricular compliance and loss of vascular elasticity, are more susceptible to volume overload and pulmonary edema.
- Perform liberal cardiac diagnostic studies, such as EKG, troponin, and echocardiography.

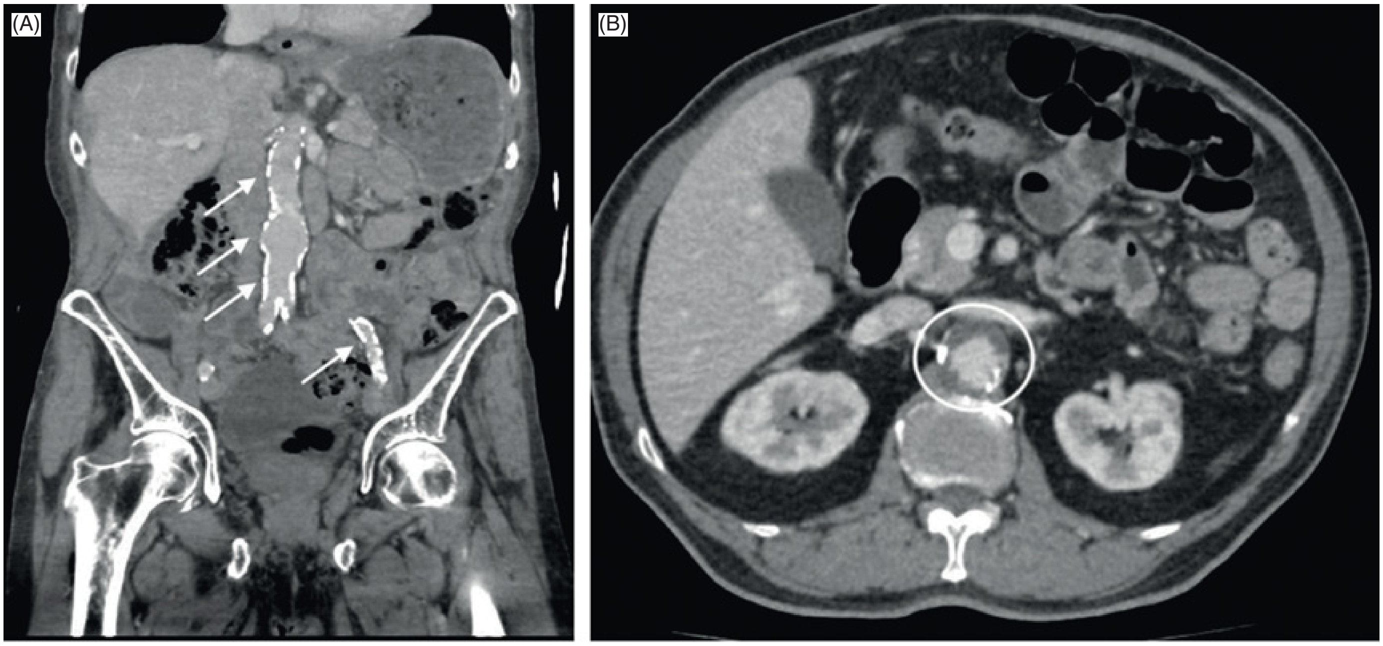


Figure 14.2 A,B Trauma patient, 92-year-old male with significant atherosclerosis of his abdominal aorta and iliac vessels (arrows; A). Trauma patient, 73-year-old male, with significant aortic disease, including atherosclerosis and mural clot (circle; B).

Disability

- Pre-existing deficits such as dementia or sequelae from prior strokes may complicate the neurological evaluation and should be considered during the primary and secondary surveys.

Exposure

Geriatric patients lose heat easily and hypothermia occurs much faster than in younger populations. Take warming precautions, especially in cold weather.

Imaging

- Cross-sectional imaging should be liberally used in the geriatric population. Occult injuries are common, and diminished physiologic reserve cause the elderly population to be less tolerant of missed injury or delayed diagnosis.
- Advanced age, along with diabetes mellitus and chronic kidney disease, is a risk factor for contrast-induced nephropathy (Figure 14.3).

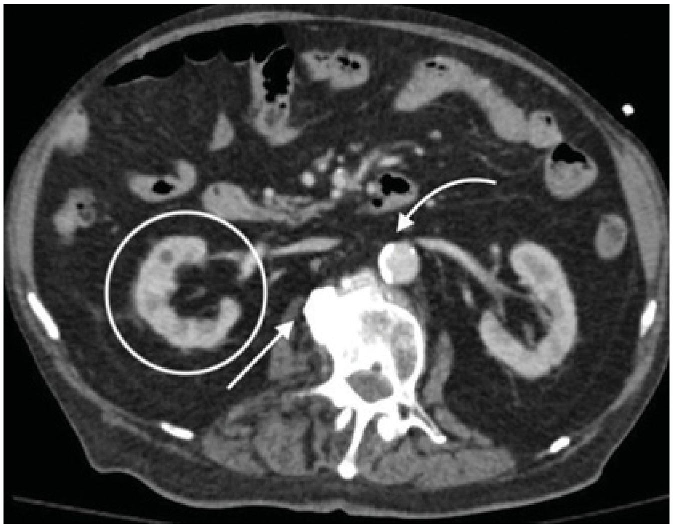


Figure 14.3 Trauma patient, 87-year-old male, with atrophic kidneys (circle), osteophytes (arrow), and aortic calcifications (curved arrow).

- Atherosclerosis and decreased ability for vasoconstriction can limit the physiologic response to hemorrhage, making early angioembolization or operative intervention a priority.
- Clinical decision rules commonly used to limit radiation exposure and imaging overuse, such as NEXUS II or the Canadian CT Head Rule, specifically exclude older patients from their algorithms.

Oral Anticoagulants

- Although warfarin is the most commonly used anticoagulant, there is increasing use of factor Xa and thrombin inhibitors.
- Prehospital use of anticoagulant medications is often unknown at the time of admission.
- Patients on anticoagulation with active internal bleeding after trauma should be considered for reversal. Intracranial hemorrhage is an absolute indication for reversal, as is active intra-abdominal and intra-thoracic bleeding.
- Warfarin
  - o Reversal can be acutely achieved with plasma infusion, or three- or four-factor prothrombin complex concentrate (PCC; factors II, IX, X, with four-factor including VII) and vitamin K.
  - o Plasma infusion is effective for warfarin reversal. It does take, however, at least four to six hours to act and requires significant fluid volume administration, which can be poorly tolerated in elderly patients, particularly those with cardiac problems. For these reasons, PCC is often favored over plasma for acute reversal.
  - o Reversal with plasma or PCC is temporary and must be accompanied by intravenous vitamin K administration. Time of onset for intravenous vitamin K is approximately six hours, timing well with the waning activity of plasma or PCC. Vitamin K administration should occur concurrent with initial reversal and should be given daily for a total of three days.
  - o Repeat doses of PCC should be avoided in order to protect against an increased risk of thrombotic complications.
- Thrombin and Factor Xa Inhibitors
  - o Idarucizumab is a direct inhibitor for patients on dabigatran, and andexanet alpha is used to reverse rivaroxaban and apixaban; however, these reversal agents are currently not widely available and remain expensive.
- Aspirin and clopidogrel are common antiplatelet medications in older patients and are known risk factors for progression of intracranial hemorrhage.
  - o Administration of platelets and/or DDAVP can be used in patients on antiplatelet therapy with active posttraumatic bleeding.

Specific Injuries

Head and Spine Trauma

- Geriatric patients often have brain atrophy allowing for increased accumulation of intracranial blood or brain swelling before developing intracranial hypertension and clinical manifestations. The threshold for CT imaging should be low in this population (Figure 14.4 A,B).
- Subdural hemorrhage is more common in elderly patients and may be clinically silent for days or weeks.
- There is a high incidence of degenerative spine disease contributing to a higher incidence of cervical spine injuries. High cervical spine injuries and central cord syndromes are more common than in youngers adults.

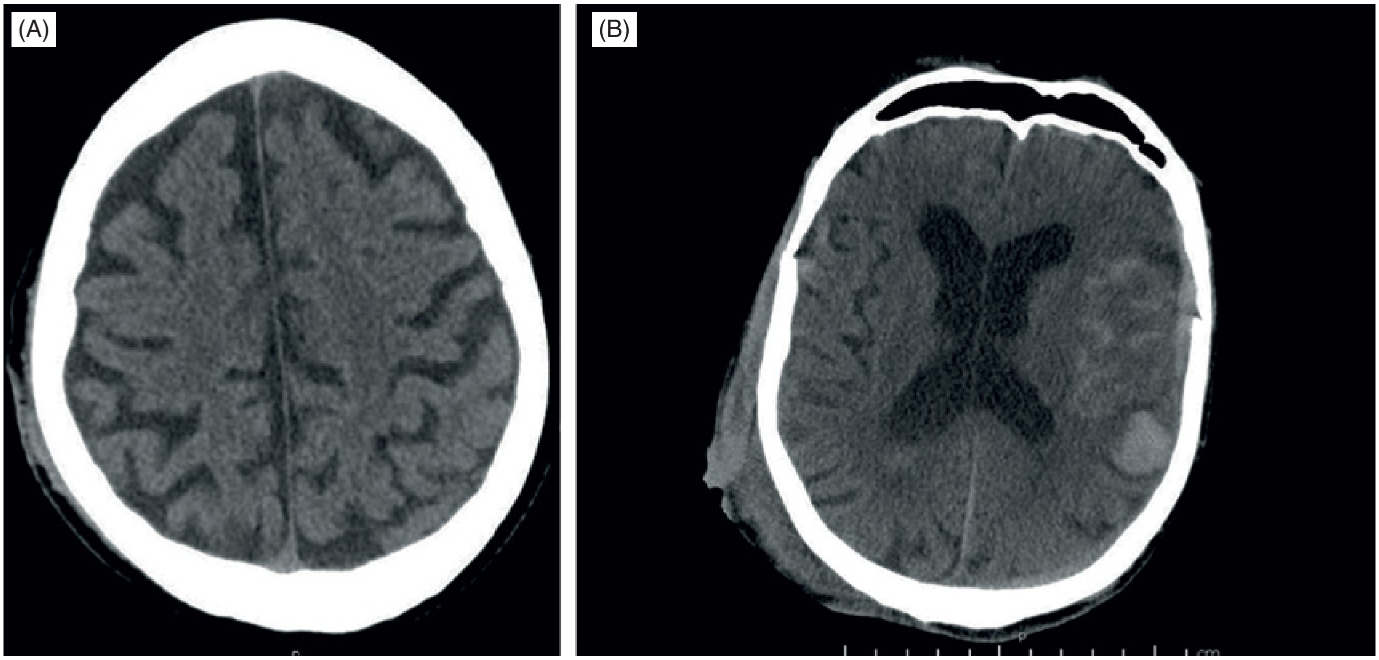


Figure 14.4 A,B Trauma patient, 87-year-old male, with significant brain atrophy (A). Trauma patient, 84-year-old male, found down with history of warfarin and aspirin use. Despite significant intracranial findings, due to baseline brain atrophy, the brain has not herniated and no significant midline shift is appreciated (B).

Chest Trauma

- Rib fractures and pulmonary contusions are the most common injuries seen in blunt thoracic trauma.
- Rib fractures are a common injury in the geriatric population and are associated with a higher morbidity and mortality than in younger patients. For this reason, aggressive management with pulmonary hygiene, multimodal pain control, and epidural analgesia should be part of the standard management protocols. Early intubation and mechanical ventilatory support should be considered in patients with borderline respiratory function.
- Blunt thoracic aortic injury is more common and therefore CT scan of the chest is recommended, even in cases with less severe trauma.

Abdominal Trauma

- Blunting of peritoneal signs in the elderly population can decrease the sensitivity and specificity of physical examination findings. Liberal CT imaging of the abdomen and pelvis is recommended.
- Nonoperative management of solid organ injuries, including liver and splenic trauma, is less successful compared to younger populations. Conversely, morbidity and mortality rates associated with laparotomy increase with age, and these factors must be considered in the discussions regarding risk and benefit of management options.

Skeletal Trauma and Pelvic Fractures

- Forearm and hip fractures are the most common skeletal injuries seen in elderly persons.
- Morbidity and mortality from hip fractures are high in the elderly, with a mortality rate of almost 30% at one year and significant loss of functional independence (Figure 14.5 A,B).

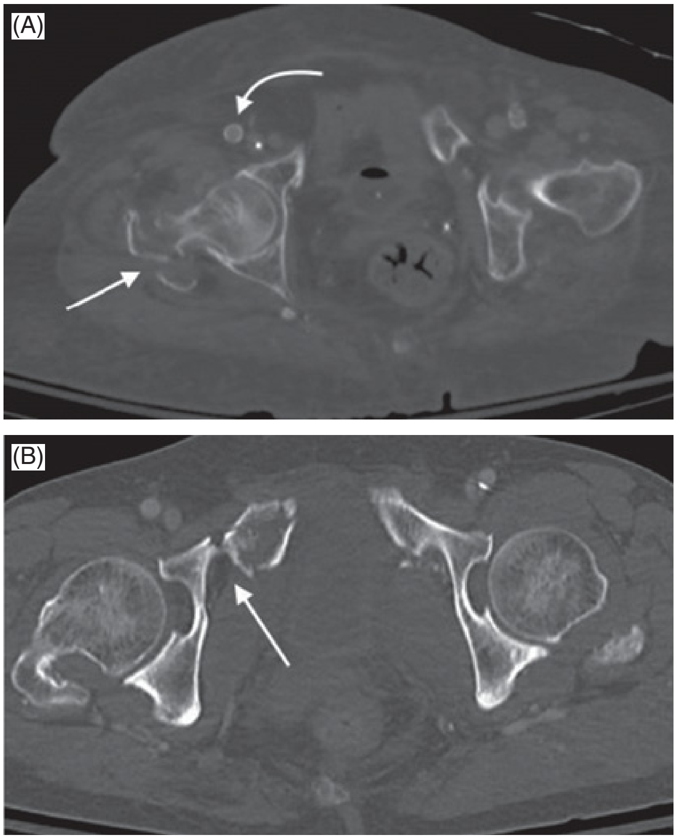


Figure 14.5 A,B Trauma patient, 90-year-old female, with an intertrochanteric femur fracture (arrow), osteopenia, and calcified femoral artery (curved arrow; A). Trauma patient, 75-year-old female with a pubic rami fracture and osteopenia that ultimately underwent angioembolization for fracture associated bleeding (B).

- Pelvic fractures in the elderly have a higher rate of mortality and complications compared to younger adults. There is a higher incidence of lateral compression fractures of the pelvis, which are associated with bleeding requiring embolization.

Special Considerations

Goals of Care

- Returning to baseline after trauma is challenging for elderly persons.
- The majority of patients who survive traumatic injury are discharged to care facilities as opposed to the home.
- Discussing goals of care and setting expectations with patients and/or family members should occur as early as possible.
- Consultation of palliative care services, when possible, should occur early.

Non-accidental Trauma

- Older patients, especially with chronic medical conditions or those who depend on others for assistance with activities of daily living, are at risk for abuse. In the US, approximately one in ten older adults are victims of elder abuse each year – a statistic that may be significantly underreported.
- "Fall" is a commonly reported mechanism in older patients with non-accidental trauma. A thorough history regarding the circumstances of the injury or fall and identify any suspicious features is imperative, as falls can occur as a result of an altercation or due to being pushed, tripped, or neglect – such as withholding a walking aid or eyeglasses – on the part of an abuser.
- The evaluating nurse or physician should take a history without a caregiver or family present if any suspicion of abuse is present.
- Detecting non-accidental trauma can pose a challenge. Atypical injury presentations or combinations, such as delayed presentation >1 day, or fractures with coexisting burns, for example, may indicate non-accidental trauma to the evaluating physician.
- Maxillofacial injuries and upper extremity injuries are most common. Fractures may be present, but skin/soft tissue injury is often the only thing seen. Bruising may be seen on the lateral aspects of the arms from being grabbed during an altercation. Bruising to the face or neck, or left-sided zygomatic fractures (from being struck by a right-handed person) has also been reported.

Suicide in the Elderly

- While suicide attempts are most commonly reported in younger persons, the suicide rate is highest in older adults, peaking in those 85 years and older.
- Males, especially white males, have the highest rate of suicide.
- Firearms are a common method of suicide in this age group, followed by suffocation, hanging, and drowning. Nontraumatic means of suicide, such as drug overdose, and so-called silent mechanisms of suicide, such as self-starvation and deliberate "accidents," are also reported.

Tips and Pitfalls

- Avoid underestimating the physiologic impact of relatively moderate trauma. Although initial hemodynamics may appear "stable," rapid deterioration is common. Liberal admission to the ICU is recommended for these patients.
- Avoid underestimating the significance of rib fractures. Respiratory decompensation and pneumonia are common complications. Early protocol-driven management of pain is important. Early endotracheal intubation should be considered for borderline cases.
- Avoid underestimating the importance of "minor" head trauma. Liberal imaging should be standard practice.
- Maintain a high index of suspicion to recognize elder abuse or signs of suicide attempt.

Chapter

15

Disaster Medicine

Joel Lombardi, Tiffany M. Abramson, and Edward J. Newton

Introduction

Disasters often occur without any warning and may result in mass casualties that can overwhelm the capacity of local and regional healthcare systems. The etiology of disasters can be man-made or natural, can be localized or effect a large geographic area, and can result in minimal harm to the population or mass casualties. The most lethal natural disasters include earthquakes, hurricanes, floods, tsunamis, snowstorms, and fires. Man-made disasters include wars, building collapses, mine cave-ins, chemical and biological exposures, nuclear accidents, and civil unrest (Figure 15.1 A,B).

Figure 15.1 A,B Haiti earthquake disaster in 2010.

Each trauma system and trauma center needs to have a well-rehearsed plan for mass casualty incidents (MCI) for different disaster scenarios (i.e., earthquakes, fires, airport accidents, different types of terrorist attack) that is based on the geographical site and availabilities of resources. A disaster plan should be as simple as possible and should be based on the daily working routine. Knowledge of disaster medicine is paramount to establish a prompt, resourceful, organized response to prevent harm, provide life-saving care, and restore safety to communities.

Epidemiology of Injuries in Mass Disasters

The type and number of casualties depends on multiple factors, including the type of disaster. The Haiti earthquake of 2010 provides an example of the array of conditions produced by such a disaster. Traumatic injuries may include burns, wounds, crush syndrome, traumatic amputations, lacerations, fractures, concussions, and weapon-related injuries. Infectious conditions can develop and include diseases such as cholera, malaria, dengue, hemorrhagic fever, typhoid, measles, tuberculosis, tetanus. Non-infectious and non-traumatic conditions can also be present and commonly include malnutrition, skin disorders, renal failure, pregnancy-related, mental health, and chronic disease complications.

Types of Disasters

A disaster is a natural or man-made event that leads to large scale loss of life, property, and/or infrastructure, which affects a community's ability to respond. There are a variety of causes of disasters including natural, chemical, biologic, radiation, nuclear, and explosive. Each type of disaster is associated with different injury patterns, risks to patients, and risks to providers, and requires a unique response.

Natural Disasters

Natural disasters are generally unpredictable. Between 2002–2011, an average of 107,000 deaths and 268 million people per year suffered from natural disasters. Natural disasters may be geophysical, meteorological, hydrological, and climatological. Based on the type of disaster, injury patterns, resource availability, and logistics may vary.

Chemical Disasters

Chemical disasters may result from failures with industrial systems, transportation, waste disposal, and chemical warfare. The Bhopal disaster in India led to the development of material safety data sheets in the United States. Ready availability of these data sheets is required in case of emergency, as they can help provide guidance for decontamination and treatment (Figure 15.2).

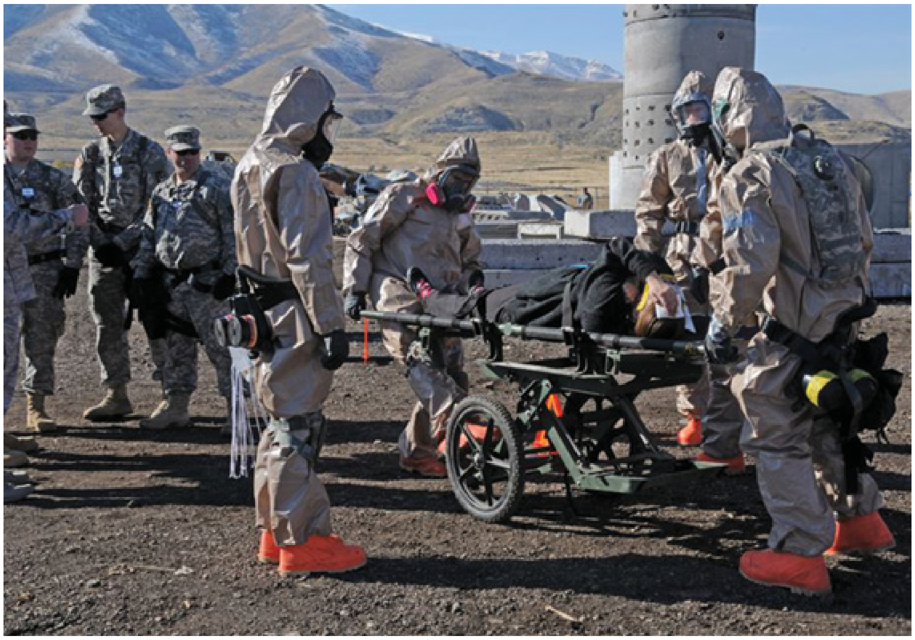


Figure 15.2 A building collapse and chemical contaminated area training exercise simulated as part of an earthquake disaster scenario. (Photo Credit: Air National Guard photo by Staff Sgt. Annie Edwards, https://www.ang.af.mil/Media/Article-Display/Article/863309/utah-ang-trains-for-disaster-response-at-vigilant-guard-2014/.)

Biological Disasters

Biological disasters are caused by exposures to toxin, microorganisms, and substance of organic origin resulting in morbidity and mortality. Examples of biological disasters include disease outbreaks, species infestations, and biological warfare agents. Additional biological disasters may coincide with other disasters requiring simultaneous treatment of both traumatic and medical injuries. Biological disasters affecting a large number of people in a locality at a particular time are known as an epidemic (e.g., plague, cholera, Ebola). When an epidemic spreads across larger regions or worldwide, it becomes a pandemic (e.g., H1N1, smallpox, tuberculosis, COVID-19). To prepare for such an event, the Center for Disease Control and Prevention (CDC) in collaboration with the US government has strategically placed stockpiles of medical countermeasures, which can be delivered in a mass causality event.

Radiation and Nuclear Energy Disasters

Nuclear science development has increased the frequency of radiation disasters. These disasters may stem from power generation, nuclear war, medicine, research, or industrial applications. Radiation exposure may lead to localized thermal injuries, systemic injuries, or increasing risk of cancers, infertility, and cataract formation.

Patients may present with contamination from skin, inhalations, ingestions, and absorptions. Symptoms are based on time since exposure and may be helpful for managing patients. Medical care should be promptly addressed by responders trained and prepared in decontamination procedures. Monitoring for radiation can also be achieved by using Geiger counters. However, immediate life-saving procedures should not be delayed for decontamination. Contaminated clothing should be removed and placed in plastic bags with care not to spread contaminants. Once a patient has had their clothing removed and any obvious particles, they no longer pose a threat to the medical team, and standard personal protective equipment (PPE) can be employed.

Radiation accumulates linearly and the US Environmental Protection Agency publishes exposure guidelines for emergency responders. It is important for medical providers to limit their exposure from the source of radiation, both by time and distance. If there is concern, N95 masks should be employed, as ingestion of radioactive particles is the most serious exposure. Furthermore, radiated environments need to be quarantined as radioactive elements may have long half-life's (Figure 15.3).

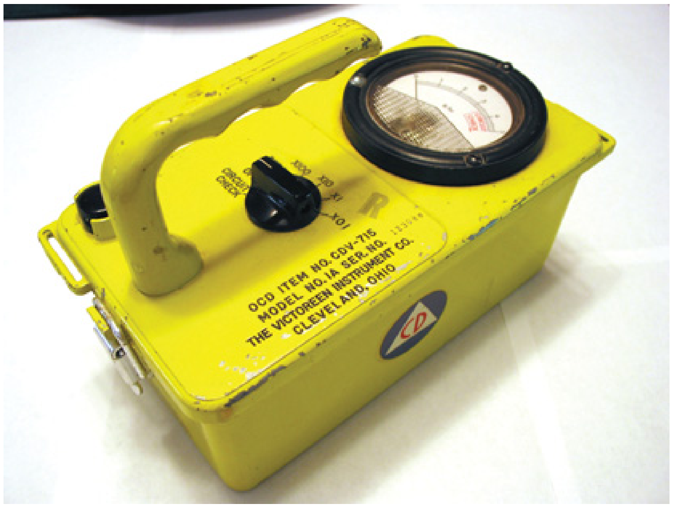


Figure 15.3 Geiger radiation counter.

Explosion Disasters

Explosive injuries occur in enclosed areas, open areas, or when structures collapse. The speed at which a substance ignites contributes to the degree of injury. The morbidity and mortality from explosions will depend on protective clothing, proximity, quantity of explosive material, physical environment, blast shrapnel, and any intentional contaminants (biologic, chemical, or nuclear). Common explosive injuries include fractures, lacerations, and brain injuries, and can be classified as primary, secondary, tertiary, quaternary, or quinary blast injuries. Additionally, everyone must be aware of the risk of secondary devices, which are additional explosives designed to target first responders, as they attempt to treat victims of the initial explosion (Figure 15.4).

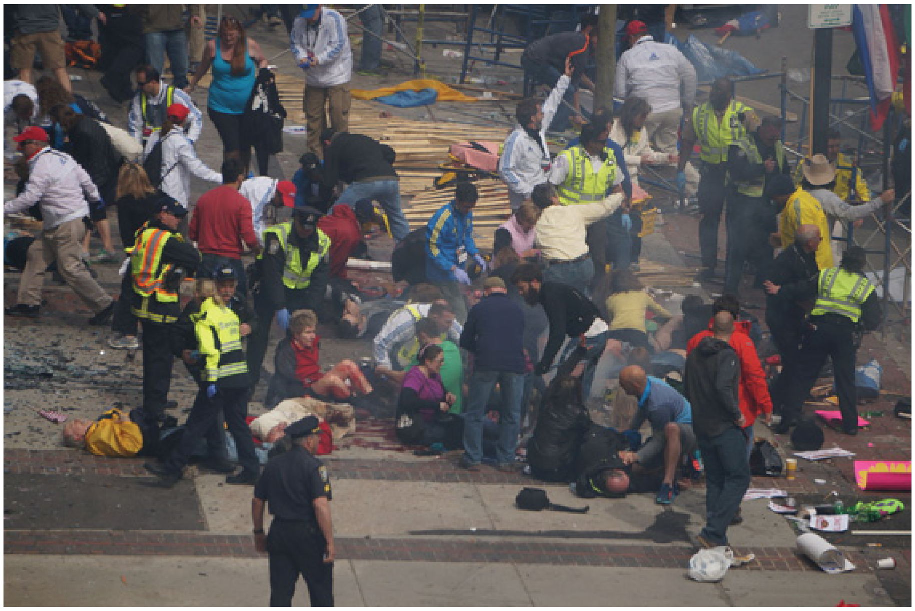


Figure 15.4 Image of the 2013 Boston Marathon Bombing. (Image Credit: Aaron "Tango" Tang https://commons.wikimedia.org/wiki/File:Boston_Marathon_explosions_(8652877581).jpg.)

Field Triage

The success of a disaster plan depends on the ability of the team to identify who will do well with minimal care, who has non-survivable injuries, and those who have severe, but survivable trauma and will benefit from the limited available resources. Effective triage at the scene and again at the hospital is one of the most critical components for the successful management of a mass disaster incident (Figure 15.5).

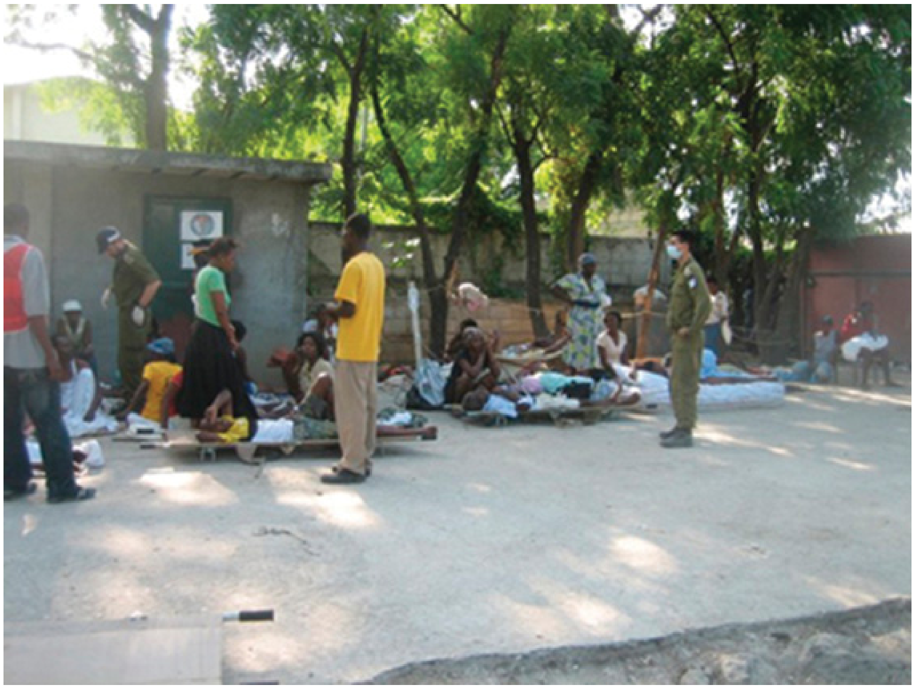
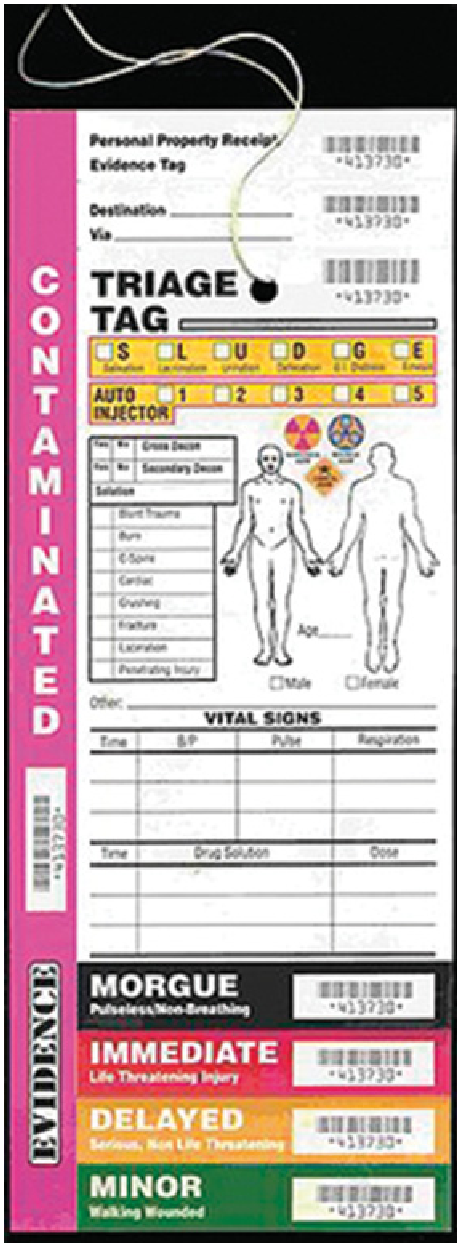


Figure 15.5 Haiti earthquake, triage in the field.

Disaster triage aims to rapidly identify, register, and assess all potential patients. The goal is rapidly doing the most good for the most people with limited resources. Triage and allocation of resources must take into account the likelihood of benefit, resources required, urgency of condition, and duration of benefit. An ideal system allows for rapid evaluation of patients with set parameters to allow for decisions made based on objective physiologic and observational data.

Triage algorithms classify patients into four categories: ambulatory (green), delayed (yellow), immediate (red), and deceased or expectant (black). Triage tags are often used to help track the classification of patients (Figure 15.6).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E
AUTO INJECTOR
1
2
3
4
5
Gross Decon
Secondary Decon
Solution
Blunt Trauma
Burn
C-Spine
Cardiac
Crushing
Fracture
Laceration
Penetrating Injury
Age
Male
Female
Other
VITAL SIGNS
Time
B/P
Pulse
Respiration
Time
Drug Solution
Dose
CONTAMINATED
EVIDENCE
MORGUE
Pulseless/Non-Breathing
IMMEDIATE
Life Threatening Injury
DELAYED
Serious, Non Life Threatening
MINOR
Walking Wounded

Figure 15.6 Color-coded tags are very useful in classifying the required level of medical care for each mass disaster victim.

While no system has been scientifically validated, various triage methods have been created based on expert consensus. The two most popular systems are the *Simple Triage and Rapid Treatment* (START) algorithm and the *Sort, Assess, Life-Saving interventions, Treatment/Transport* (SALT) algorithm. START takes into account walking, breathing, perfusion, and mental status to categorize patients allowing only for airway positioning. Of note, there is a modified version referred to as JumpStart for pediatric patients (0–8 years of age), which accounts for normal pediatric vital signs and allows for five rescue breaths in an apneic patient who still has a peripheral pulse. The SALT algorithm allows for more interventions during the initial triage, including controlling major hemorrhage, opening the airway, two rescue breaths for children, chest decompression, and auto-injector antidote administration.

A much more detailed clinical examination by an experienced physician is needed for a more reliable triage. The triage should take place outside the emergency room and can be performed in conjunction with the trauma team.

Emergency Response

Prompt, organized emergency response is paramount in the management of disasters. The initial period after a disaster is critically important to the success of the management operation and can save lives. The biggest failure in disasters and MCIs is failure of communication, so having a pre-planned method of sending out alerts and communicating throughout the hospital is key. Additionally, given the low frequencies of these events and providers working outside of their usual environment, frequent drilling regarding roles and provider safety will allow for improved operations.

Incident Command

The incident command system is an organized hierarchical structure capable of command and control over a disaster. The Federal National Incident Management System utilizes the Incident Command System (ICS) to support emergency response personnel during disaster operations. The goal of ICS is to facilitate a consistent response to an incident by using a standardized organizational structure that can be adjusted in a familiar fashion based on the level of need. When multiple agencies are responding to an MCI, common terminology and operating procedures for supervising personnel, facilities, equipment, and communications allows for seamless integration of services.

Field Safety

Disaster responders must be aware of the environmental and physical hazards that exist at the scene of a disaster. PPE may be required and will vary depending on the type of disaster. Patient decontamination may be necessary prior to providing medical evaluation and treatment. If a violent or dangerous situation develops, the first priority should be retreating from the scene (Figure 15.7 A,B).

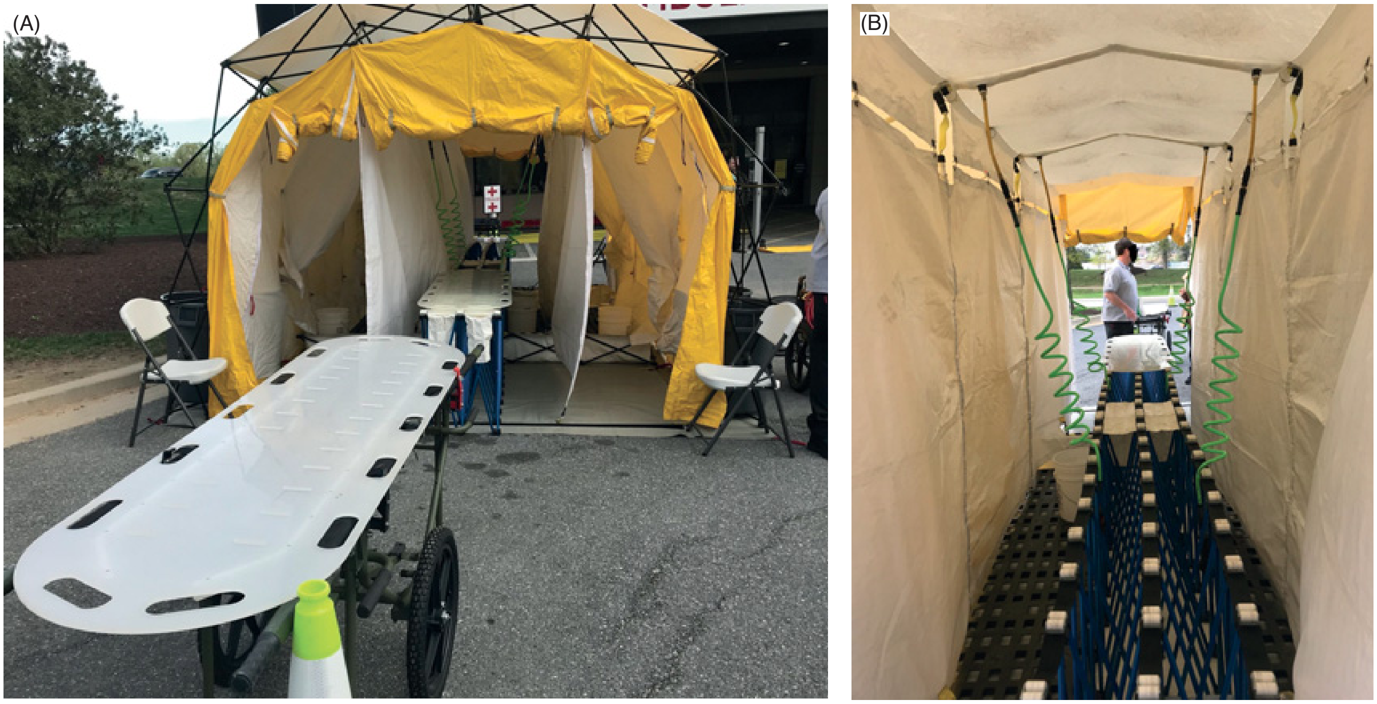

Figure 15.7 A,B Patient decontamination unit outside emergency department entrance (A). Decontamination should always take place outside the emergency room (B).

Supplies

Agencies and hospitals must have a plan to immediately distribute supplies during a disaster. The CDC maintains a Strategic National Stockpile of life-saving saving pharmaceuticals and medical supplies for use in public health emergencies. This stockpile is strategically positioned around the nation so that it can be distributed to any area of disaster within 12 hours. Each package contains 50 tons of emergency medical resources. Examples of materials include medications, antidotes, vaccines, medical devices, and supplies (Figure 15.8).

Figure 15.8 The Strategic National Stockpile contains pharmaceuticals and medical supplies ready to be deployed to a disaster. (Photo courtesy of the Strategic National Stockpile, US Department of Health and Human Services.)

Logistics

Disaster management is not commonly encountered and hospital personnel may find logistical challenges in obtaining and providing resources. The onsite emergency operations command should notify hospitals in the local area of mass causalities and the total number of injured to expect to be transferred. Furthermore, hospitals should report the number of received and expected patients, capacity, bed numbers, and operating room availability to the emergency operations center. In some instances, an immediate response is needed at a disaster site and temporary health care facilities must be brought to disaster zones. These may include floating, flying, inflatable, and/or drivable facilities that can be rapidly deployed to provide humanitarian and medical support.

Guidelines for Rescue Efforts

Regional coordination is essential to transition patients with special problems to definitive care. Burn, major trauma, neurosurgical, poisoned, and isolation patients require specialized services that may need regional coordination for treatment. A single hospital may be overwhelmed with multiple patients requiring intensive care and transporting patients directly to a specialty center via ground or air may be appropriate.

Rescue efforts are often uncoordinated initially. A central command structure to direct resources to areas with the greatest need is highly desirable but depends on the cooperation of multiple organizations, often nongovernmental organizations (NGOs), to be effective.

Dead bodies are often disposed of hastily in disasters without adequate methods of identification or notification of relatives. Victims should be photographed before burial or cremation for later identification. Disaster Mortuary Operational Response Teams (DMORTs) may be deployed at the request of local authorities to assist local mortuary services. They are composed of funeral directors, medical examiners, pathologists, forensic anthropologists, fingerprint specialists, forensic odontologists, dental assistants, administrative specialists, and security specialists.

Subacute Care

Relief efforts must transition from the acute phase where the focus is on rescue and individual patient care to the subacute phase (14 days to months), where the focus is on caring for the larger population. In this phase, the priorities are establishing shelters, providing clean food and water supplies, reuniting families, ensuring security, treating infectious diseases that emerge, controlling insect disease vectors, vaccinations, re-establishing medical care for chronic medical problems, and providing rehabilitation and psychiatric support services. Restoring infrastructure, including communications, road access, and electricity, are also essential priorities.

Outbreaks of infectious diseases including cholera are common after floods, tsunamis, and hurricanes but relatively uncommon after earthquakes. However, other conditions such as respiratory infections, psychological problems, addiction, and dental problems are common among refugee camps.

Injuries and Treatment

The medical team may need to drastically modify its usual standards of care, in an attempt to preserve the available limited resources for the salvageable group of patients with severe trauma. Such changes of usual practices of care may include the following:

(a) No resources should be spent on nonsalvageable victims.
(b) Complex fractures are best stabilized by casts or external fixation rather than intramedullary rodding (Figure 15.9, Figure 15.10 A–D).

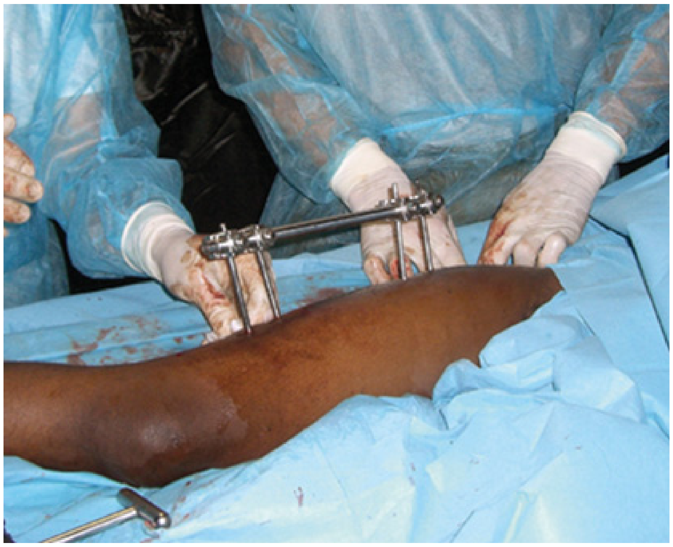

Figure 15.9 Haiti earthquake. Severe long-bone fractures are managed with external fixation because of the lack of resources and the heavily contaminated wounds.

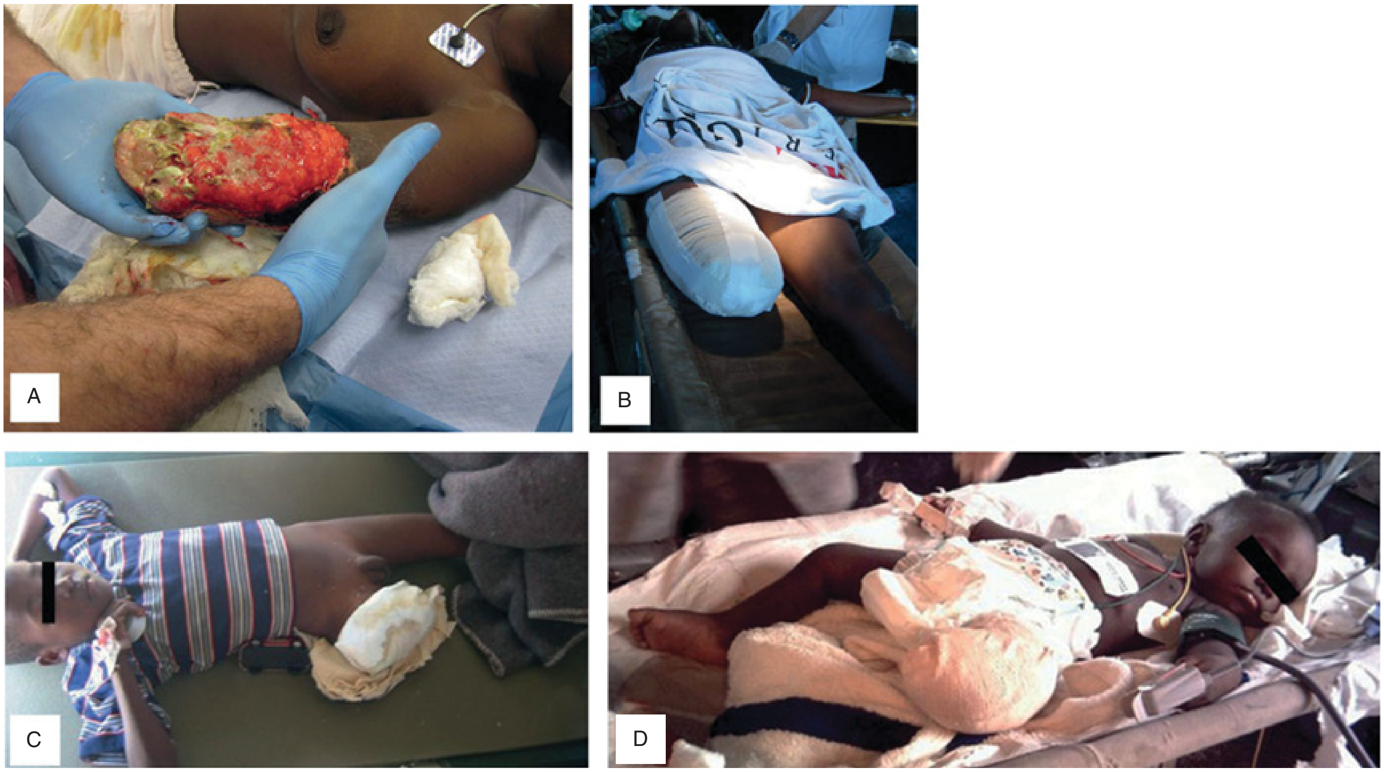

Figure 15.10 A–D Haiti earthquake. Amputations were the most common major operation, very often because of open fractures receiving delayed or suboptimal care.

(c) Radiology, especially the CT scanner, is a major bottleneck of patient flow in mass disaster events. CT scan and radiology, in general, should be used judiciously, and certainly below the usual standards of care.

- Patients with clinical hemothorax might have a chest drain inserted without chest X-rays. Chest X-rays should be reserved for patients with certain types of trauma, such as blast injuries, missile injuries, or cases that cannot be evaluated clinically.
- Radiography for cervical spine clearance or liberal pelvic X-rays is deferred for a later stage.
- Urgent CT scan should be reserved only for selected patients with significant potentially salvageable head injuries. Minor head injuries (GCS >13) do not undergo CT scan evaluation.
- CT scan of the chest or abdomen is deferred for a later stage. Clinical examination, FAST, and DPA should be the primary means of abdominal evaluation.
- Suspected extremity fractures may be splinted without radiological confirmation.
- Patients undergoing radiological investigations in the radiology suite should not return to the emergency department. It is a one-way route! Failure to follow this rule may result in bottlenecks.

(d) Laboratory studies should be kept to a minimum. The only routine lab is hemoglobin. Arterial blood gas, serum electrolytes, CPK, and coagulation studies are reserved only for certain victims, such as chemical terror attacks, crush injuries, and inhalation injuries.

Disaster-related injuries are often similar to those encountered in typical trauma emergency medicine and should be managed similarly, based on resource availability. Specific injury patterns unique to disasters and rescue operations are discussed as follows.

Entrapment and Field Amputation

Earthquakes, landslides, explosions, and tsunamis are examples of disasters where patients may be pinned, buried, and submerged. Rescue operations are aimed at rapidly accessing the patient to examine and resuscitate as needed. Rescuer safety is paramount in these situations, and considerations must be taken to account for possible encounters with thermal or chemical dangers, electrocutions, poor air quality, hazardous exposure, and the possibility of further entrapment.

Surgical field amputation may be necessary to save the life of an entrapped victim. As this procedure is not commonly performed or a routine part of emergency medicine or surgical training, treatment protocols have been proposed to increase survivability.

Emergency Medical Services (EMS) agencies may choose to have a traumatic amputation protocol to guide treatment. One example is the development of a Hospital Emergency Response Team (HERT), which is a physician-led team designed to bring medical expertise from the hospital to the field for specialized circumstances that may require amputations or other field operative interventions. The team should be multidisciplinary and include trauma surgeons, emergency physicians, and nurses. It should be well trained and hold training drills on a regular basis. The protective gear and equipment should be stored at well-marked and secured places. The team should be in protective gear and ready for dispatch to scene, shortly after activation, and assemble on the helipad or the ambulance ramp within 20–30 minutes. The equipment should include airway supplies and medications, analgesics, topical hemostatics, and amputation surgical instruments. The purpose of the team is to provide additional support to the prehospital providers, to aid in the extrication and stabilization of complicated patients and expedite their transport to the hospital setting (Figure 15.11 A–C, Figure 15.12 A,B, Figures 15.13 A,B, Figure 15.14).

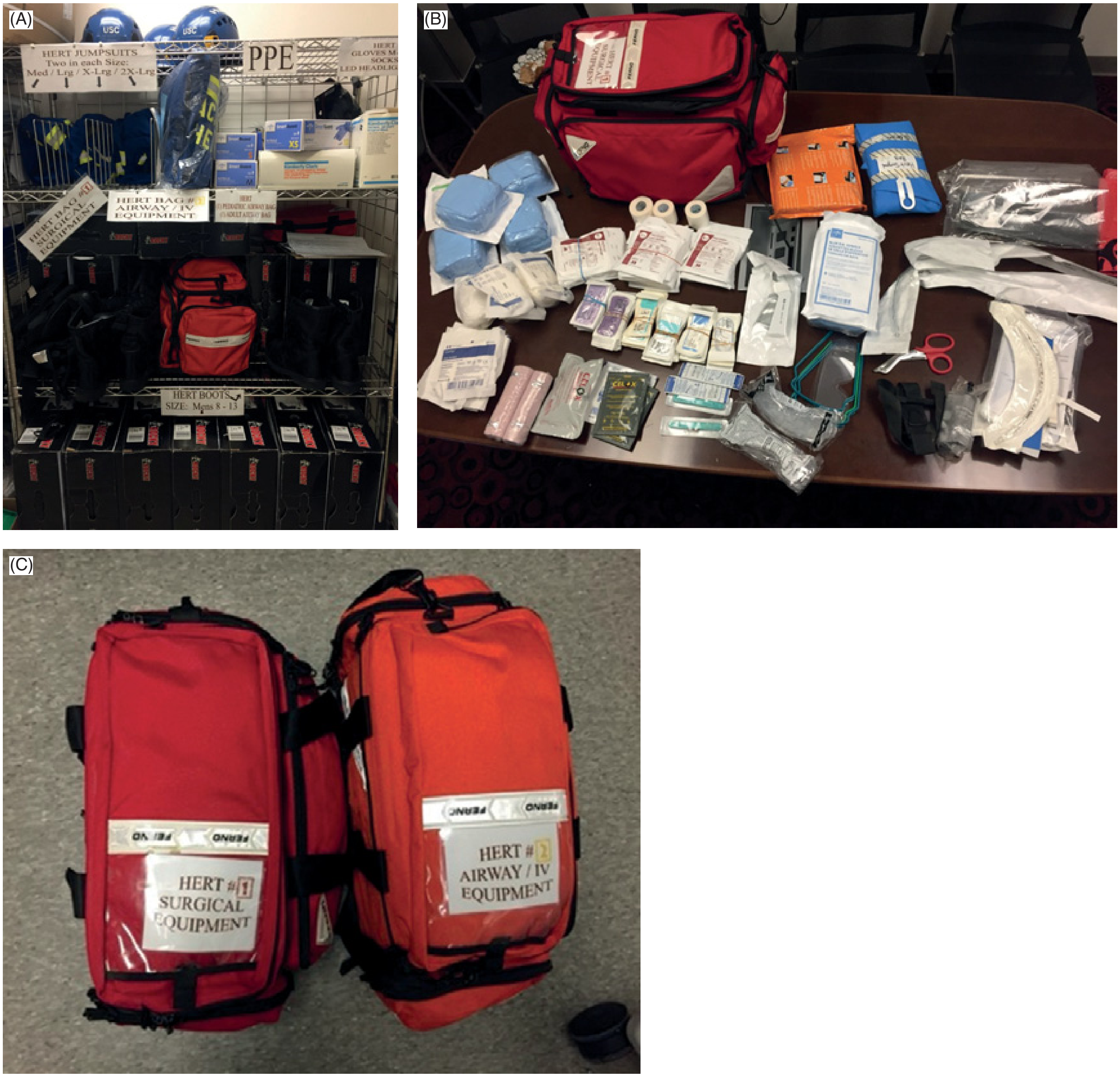
(A)
HERT JUMPSUITS
Two in each Size:
Med / Lrg / X-Lrg / 2X-Lrg
PPE
HERT
GLOVES M
SOCKS
LED HEADLIG
HERT BAG #1
SURGICAL
EQUIPMENT
HERT BAG #2
AIRWAY / IV
EQUIPMENT
HERT
(1) PEDIATRIC AIRWAY BAG
(1) ADULT AIRWAY BAG
HERT BOOTS
SIZE: Mens 8 - 13
(B)
(C)
HERT #1
SURGICAL
EQUIPMENT
HERT #2
AIRWAY / IV
EQUIPMENT

Figure 15.11 A–C HERT: PPE and supplies. An area of the hospital convenient to the emergency department is designated for the storage of PPE and supplies for HERT activation. Separate bags for the surgeon, emergency provider, and nurse are stored and checked regularly. The contents of the bags vary based on institution and environment but consist of basic instruments for hemorrhage control, amputation, airway management, resuscitation, and hemostasis.

Figure 15.12 A,B HERT members airlifted for on-scene surgical intervention on a trapped victim.

(A)
(B)
LAC+USC HERT
JENSEN PRECAST

Figures 15.13 A,B Extrication drill for HERT team members.

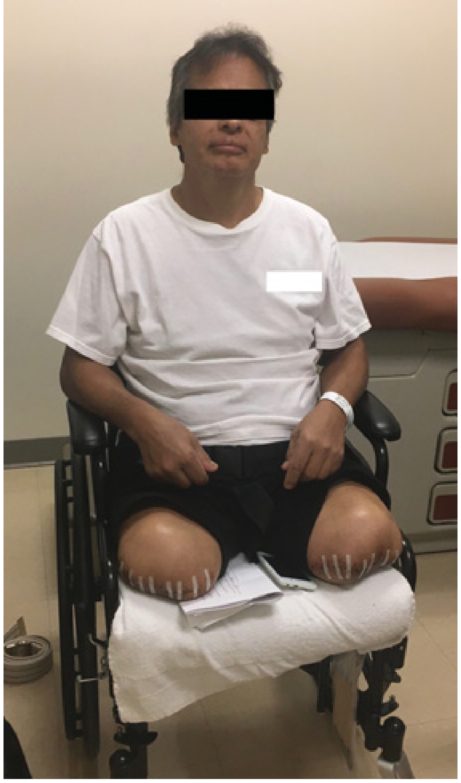
[redacted]

Figure 15.14 Patient with on-scene bilateral leg amputations, following entrapment in an enclosed hopper.

Compartment Syndrome

Compartment syndrome is a common problem in crush injuries, very often after earthquakes. The clinical presentation, diagnosis, prevention, and treatment are described in Chapter 10, Extremity Compartment Syndrome. In addition to acute kidney injury, it can cause muscle necrosis which can result in permanent disability and often amputation.

The ability to recognize and treat compartment syndrome by good hydration, emergency fasciotomy, or amputation is essential to deal with a large number of casualties with crushed limbs (Figure 15.15).

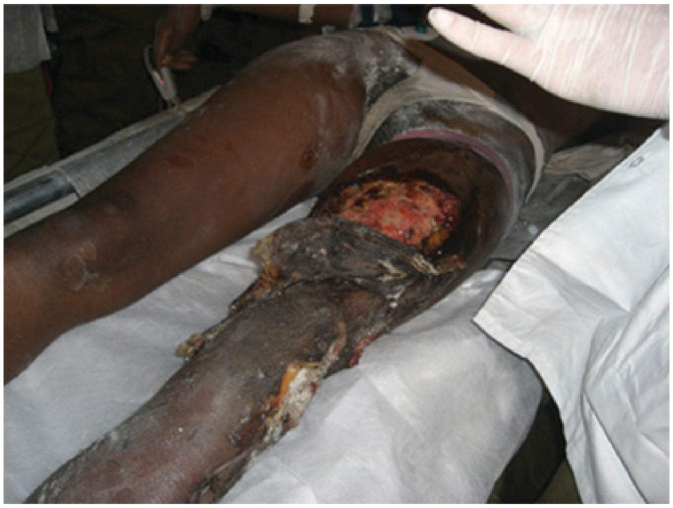

Figure 15.15 Haiti earthquake: Victim was rescued from the debris of her collapsed home after six days. There is a necrotic, infected wound of her left thigh. She succumbed to renal failure the following day.

Psychological Impact

Disaster survivors and medical providers suffer from behavioral health problems such as posttraumatic stress disorder and substance abuse after losing multiple friends and family members, their homes, employment, and all of their possessions. The World Health Organization estimates that 15–20% of those who experience humanitarian emergencies have mild to moderate depression and anxiety. Psychiatric support services are typically not available in the acute phase of a disaster and often are limited by language and cultural barriers, but community-based support services should be organized early in the course of the recovery and have proven effective.

Disaster Preparedness and Planning

By improving preparedness and educating people on how they can take action in a disaster, communities can stay protected and minimize disaster-related morbidity and mortality.

Prehospital

A) Warnings and Signs

Programs should be in place to notify emergency agencies of potential disasters. With present-day advancements in telecommunication, seamless integrated notification systems have been established. The Federal Emergency Management Agency (FEMA) operates the Integrated Public Alert and Warning System (IPAWS), which allows information to be sent to civilians via various emergency alerting systems. These alerts are emergency messages sent to civilians' mobile devices by authorized government authorities, alerting them of emergencies and disasters in their area. The ShakeAlert system currently employed on the West Coast of the US utilizes the IPAWS and allows geological survey infrastructure to distribute earthquake alerts through various outlets smartphone applications, social media providers, and other electronic alert technologies as they develop (Figure 15.16).

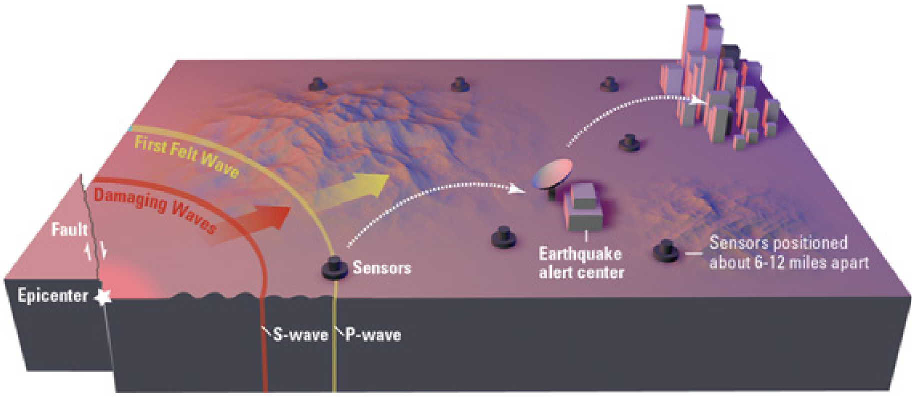

Figure 15.16 ShakeAlert warning messages can be transmitted faster than the speed of shaking waves traveling through the earth. Image created by Erin Burkett (USGS) and Jeff Goertzen (Orange County Register). Courtesy of the US Geological Survey ShakeAlert Project.

B) Planning

Prehospital agencies and hospitals should have protocols and policies in place for providers to follow during disasters. These should outline the disaster resource centers, chain of command, equipment and medication stocks and locations, evacuation routes, coordinated strategies with local hospitals, communications, and mobile deployment.

C) Prevention

Disaster prevention aims to mitigate and prepare the community and emergency services agencies for a catastrophe. Education in skills and systems knowledge will prepare agencies for potential disasters. Ready.gov is a national public service campaign to promote preparedness through public involvement so the citizen of the US can be prepared to respond and mitigate natural and man-made disasters.

The United Nations international strategy for disaster reduction outlines the framework and guidelines for countries and international efforts on disaster prevention. National campaigns exist such as “Stop the Bleed” (www.stopthebleed.org) to educate civilians on emergency management before professional help arrives.

Hospital

A) Warnings and Signs

Notification systems between EMS and hospitals are required to prepare hospitals to deal with disasters. Most EMS systems are required by their regulatory authorities to have two-way communication capabilities between their providers and the hospital. Modern software applications provide rapid notification and sharing of data by EMS personnel on the scene to the emergency departments and to medical specialists. Regional hospitals must have a policy on disaster notification, which outlines how they will prepare for patients brought with EMS from a local disaster.

B) Planning

Hospitals must perform a hazard vulnerability analysis to determine where resources will be allocated during disaster response. Hospitals must determine which disaster they may be at high-risk of providing care for (e.g., proximity to a nuclear power plant, water dam, chemical, or weapons manufacturing facilities). Hospitals should engage in developing plans, relationships, and procedures to enhance hospital surge capacity for responding to a disaster event in their community.

C) Prevention

Hospital employees must train and practice how they will respond to a disaster. Formal drills and didactics should be performed regularly and may choose to involve community members, local first responders, and emergency agencies.

Disaster Resources

Local Assistance

During a disaster the local government provides the initial emergency response through emergency medical service agencies. They are responsible for activating an Emergency Operations Center (EOC) and plan. They will coordinate with public and probate organizations, notify the state emergency management, and activate mutual aid. Ultimately, they may request assistance from the state if the disaster is beyond their control. The state government will review and can decide to proclaim a state of emergency and request federal assistance.

National Assistance

The federal government will conduct a damage assessment with state and local governments and determine if federal assistance is needed. If approved, they will activate the federal response plan, establish emergency support teams, and identify emergency support function as needed. FEMA manages and deploys Urban Search and Rescue Task Force (US&R Task Force) to large-scale national disasters. There are 28 teams located across the US and are composed of medical, technical, and search and rescue personnel.

International Assistance

Large humanitarian networks such as the Red Cross maintain teams of trained disaster responders and have relief supplies positioned worldwide to deliver immediate support to international disasters. The United Nations Office of Disaster Risk Reduction coordinates information exchange, forums, and discussions between international stakeholders to share experiences and create strategies for the implementation of global disaster risk reduction.

Tips and Pitfalls

1. Planning
    - Regional coordination is essential to guide response efforts.
    - Education and preparedness measures help minimize injuries.
    - Hospitals must perform a hazard vulnerability analysis to determine where resources will be allocated during disaster response and determine for which disasters they may be at higher risk.
2. Communication
    - Pre-established communication plan within hospitals.
    - Integrated warning systems provide alerts to communities, first responders, and hospitals.
    - Modern technology allows for the public to receive notifications from the IPAWS.
3. Safety
    - Disaster responders must be aware of hazards that exist in the field and be knowledgeable on the use of PPE that may be required.
    - Scene safety is an important consideration for rescuers on the scene of a disaster.
4. Drills/practice
    - First responders, hospitals, and communities must train and practice how they will respond to a disaster.
    - Training in specialized procedures (i.e., field amputation) is important to familiarize providers with scenarios not commonly encountered.

Chapter 16

Central Venous Access

Meghan Lewis and Andrea Austin

General Principles

- Central venous access is obtained via the internal jugular vein (IJV), subclavian vein (SCV), or femoral vein.
- Central venous catheter (CVC) use should be minimized, and lines removed as soon as possible to prevent infection.
- Indications for placement include:
  - ○ Administration of vasopressors or other venous irritants
  - ○ Parental nutrition
  - ○ Hemodynamic monitoring
    - ■ Central venous pressure monitoring
    - ■ Central venous oxygen saturation
    - ■ Pulmonary artery catheter
  - ○ Facilitation of transvenous pacing (right IJV or left SCV only)
  - ○ Large volume resuscitation
  - ○ Peripheral access is unobtainable
- Ultrasound guidance can increase the accuracy of CVC placement and may decrease the number of attempts, and therefore the associated complications.

Instruments

- Multiple commercially available kits exist for CVC placement. The operator should ensure familiarity with the specific product prior to use. General contents of a kit include 18-gauge needle for accessing the vein, 10 cc syringe, guidewire, dilator (sometimes multiple), and catheter (Figure 16.1).

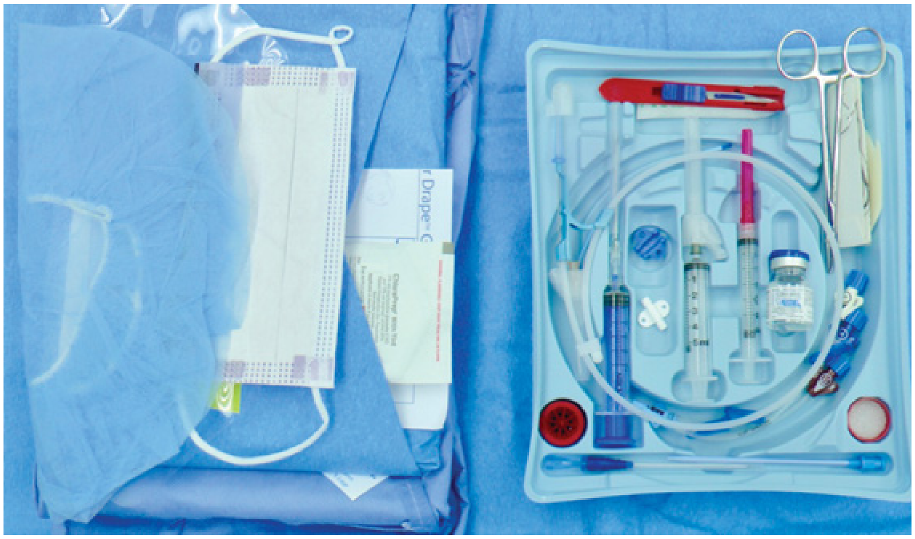

Figure 16.1 General contents of a commercially available central venous catheter kit.

- Additional equipment that may not be included in the kits are chlorhexidine prep, sterile drapes, gloves, gown, local anesthetic, appropriately sized needles, additional syringes, sterile saline, chlorhexidine-impregnated sponge, and sterile dressings.
- Ultrasound equipment, a high-frequency linear probe (greater than or equal to 7 MHz for optimal resolution of superficial structures), and a sterile probe cover are required for ultrasound-guidance.
- Multiple types of catheters are available. The most common CVC placed is the 7-Fr standard triple lumen catheter. It allows for simultaneous administration of medications and/or blood products through three separate lumens. For patients requiring rapid, large-volume resuscitation, a single lumen 8.5-Fr percutaneous sheath introducer is recommended. If a transvenous pacer is necessary, a 6-Fr percutaneous sheath is recommended. Use of a larger catheter will

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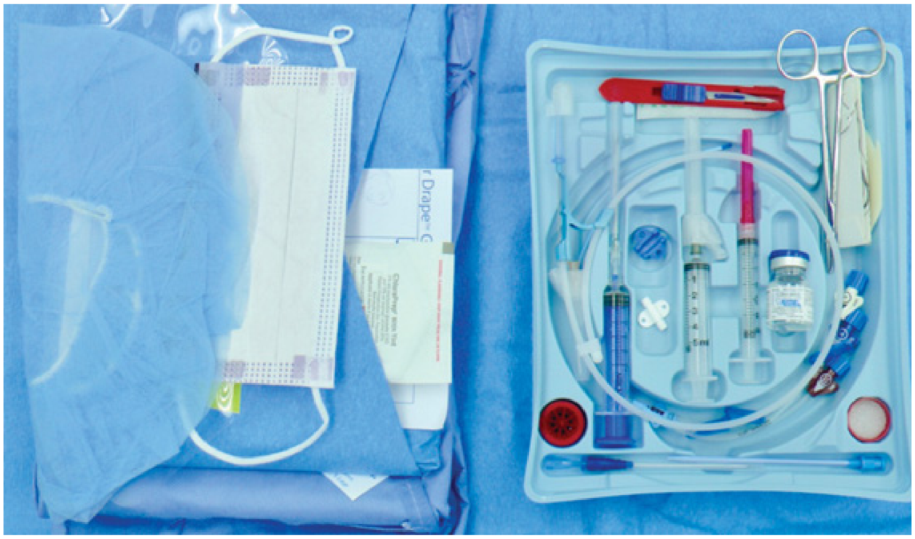

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result in blood backing up into the catheter and leaking around the pacer wire.
- Antiseptic (chlorhexidine/silver sulfadiazine) or antibiotic-bonded (minocycline/rifampin) catheters should be considered if the duration of the catheter stay is expected to be >5 days.

Preprocedure

- Consent from the patient or family member should be obtained whenever possible.
- Elective procedures should be performed under full sterile precautions, including full-body draping, gown, mask, and sterile gloves. Skin disinfection with chlorhexidine is superior to alcohol or betadine. The skin entry site should be covered with dry gauze or transparent breathable dressing. When ultrasound is used, the probe should be covered with a sterile probe cover.

Positioning and Landmarks

Internal Jugular Vein

- The patient should be placed in the Trendelenburg position. This position dilates the IJV and also reduces the risk of air embolism. Ideal positioning involves turning the patient's head 45 degrees to the contralateral shoulder. Alternatively, a neutral position can be used for patients requiring cervical spine precautions.
- Surface anatomic landmarks include the sternocleidomastoid muscle, its division into sternal and clavicular heads, as well as the clavicle, the external jugular vein, and the suprasternal notch (Figure 16.2).
- Several approaches have been described; however, the use of ultrasonography is now considered standard of care. The landmark approaches should be reserved for situations in which ultrasound is not available.
- In the most common landmark approach, the skin is punctured at a 30-degree angle at the apex of the division of the sternocleidomastoid muscle and advanced toward the ipsilateral nipple.
- In the ultrasound-guided approach the IJV is identified as the lateral, compressible vessel in the neck. The carotid artery is located medially, and pulsation of the artery can be observed on ultrasound. The probe is held in the operator's nondominant hand and can be oriented to visualize the vein in the short axis, long axis, or oblique axis. The skin is punctured at a 30–45-degree angle, and the needle is visualized in real time as it is advanced into the vein (Figure 16.3, Figure 16.4).

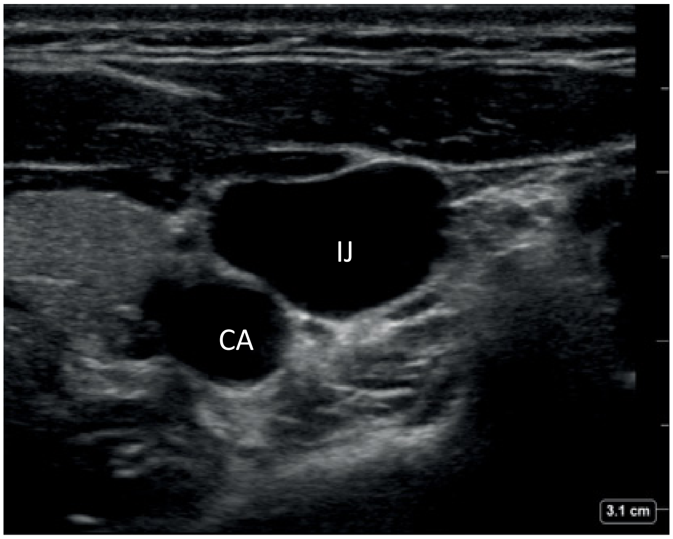


Figure 16.3 Ultrasound view of the neck demonstrating the IJV, which is the lateral, compressible vessel. The carotid artery is located medially, and pulsation can be observed.

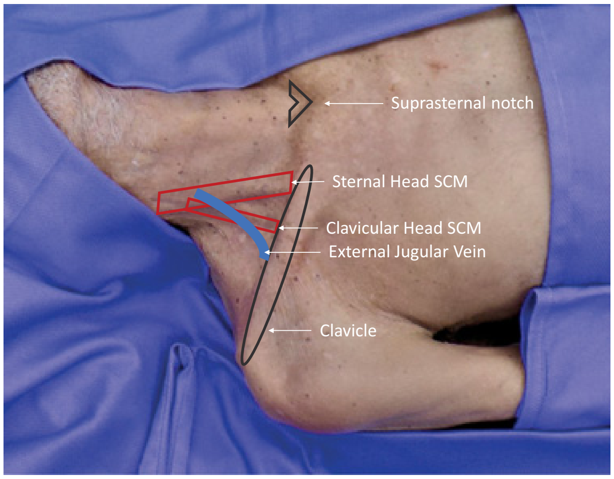


Figure 16.2 Surface anatomic landmarks for placement of an IJV or SCV central venous catheter.

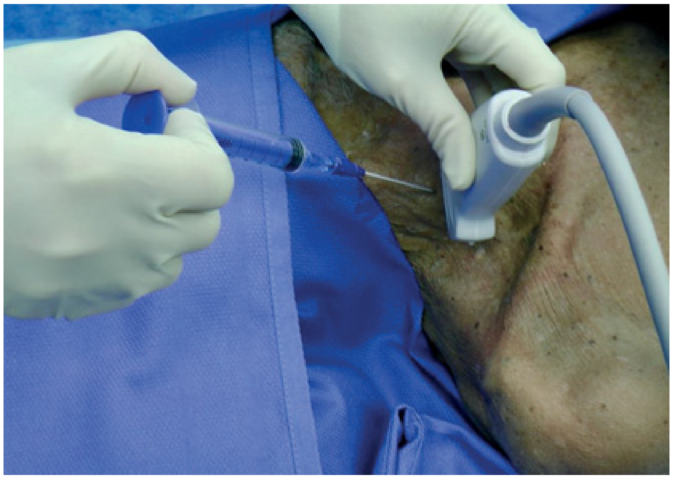


Figure 16.4 Access of the IJV using ultrasound guidance.

Subclavian Vein

- The patient should be placed in the Trendelenburg position to reduce the risk of air embolism.
- Ideal positioning involves a roll placed under the patient's shoulders. Alternatively, a neutral position can be used for patients requiring cervical or thoracic spine precautions.
- Surface anatomic landmarks of the infra-clavicular portion include the middle of clavicle and the sternal notch.
- Under ultrasound guidance, the IJV should first be located as described above. The ultrasound probe should then be moved caudally into the supraclavicular fossa, where the confluence of the IJV and SCV is identified. The SCV is anterior to the subclavian artery (Figure 16.5).

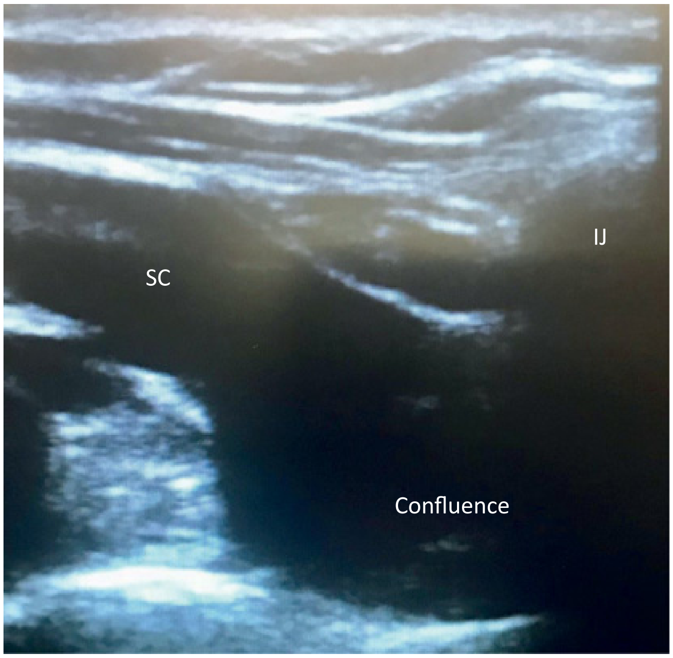


Figure 16.5 Ultrasound view of the supraclavicular fossa, where the confluence of the IJV and SCV is identified.

- Using the landmark approach, the nondominant hand of the operator is placed over the clavicle, with the index finger in the sternal notch and the thumb at the angle of the clavicle in the deltopectoral groove (Figure 16.6).

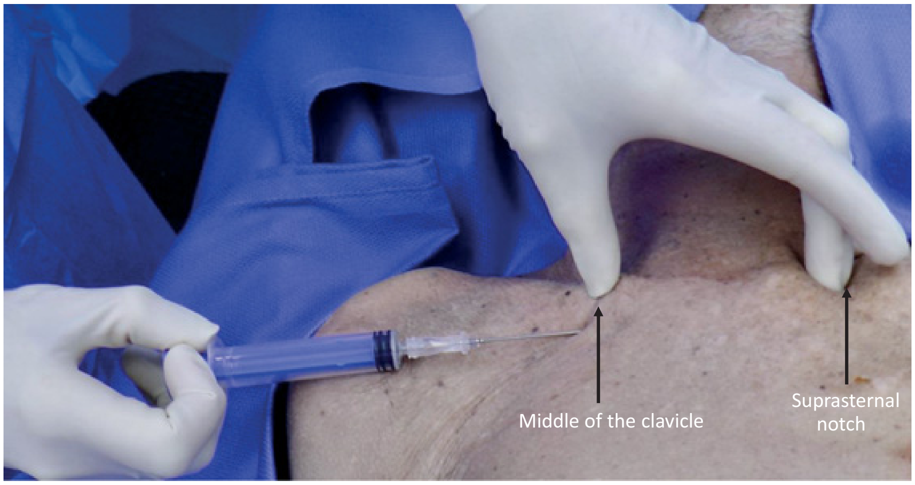


Figure 16.6 Access of the SCV using the landmark approach.

- The SCV should be punctured as it crosses under the clavicle, at the lateral border of the medial third of the clavicle. The skin should therefore be punctured 1–2 cm inferior and lateral to this point.
- The needle is advanced inferior to the clavicle while aiming at the sternal notch.

Femoral Vein

- The patient can be positioned supine or in the reverse Trendelenburg position. The leg can be abducted and externally rotated up to 15 degrees.
- Surface anatomic landmarks include the anterior superior iliac spine and the pubic tubercle. The inguinal ligament

courses between these structures. The femoral sheath is contained in the femoral triangle, which is bound superiorly by the inguinal ligament. The vein is medial to the femoral artery (Figure 16.7).

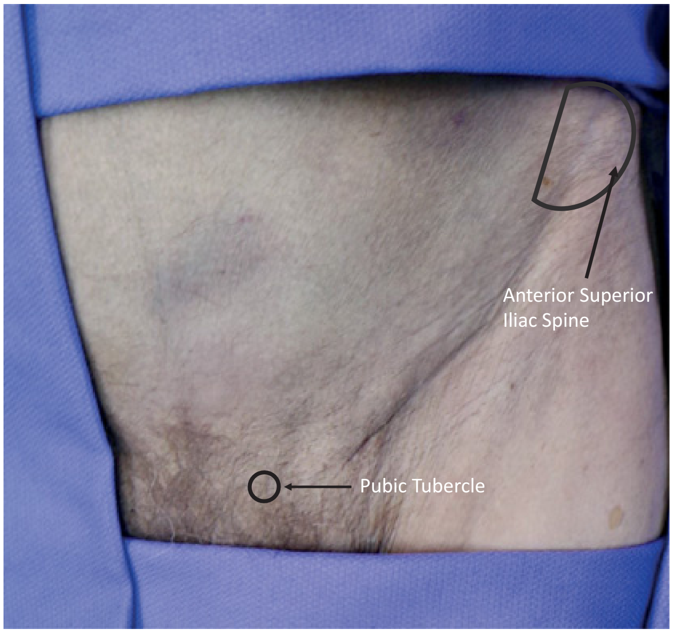


Figure 16.7 Surface anatomic landmarks for placement of a femoral venous catheter.

- Under ultrasound guidance, the vein is the compressible vessel located medially. The femoral artery is lateral, and the pulsation can be observed on ultrasound.
- The vein should be punctured inferior to the inguinal ligament (Figure 16.8). If there is a palpable pulse, the femoral vein can be found approximately 1 cm medial to it. Alternatively, ultrasound guidance can be used to identify the vein.

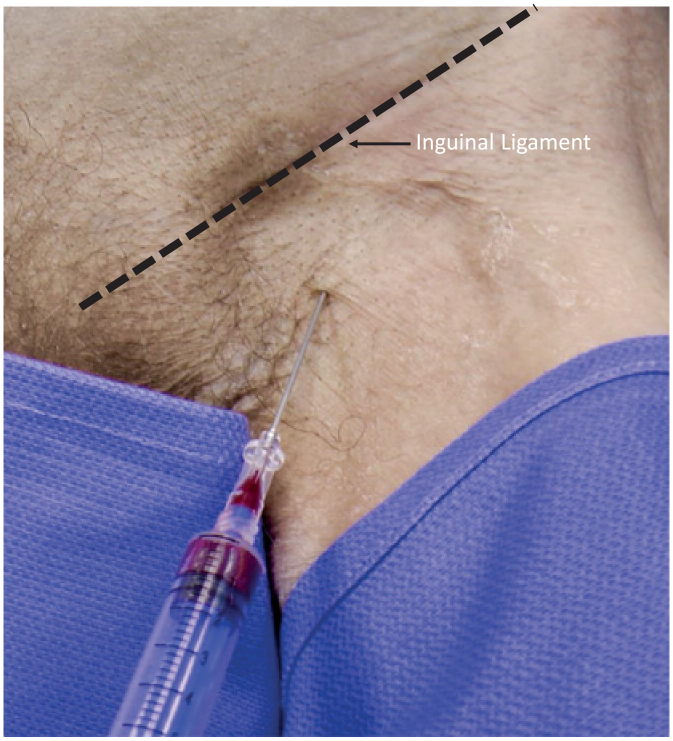


Figure 16.8 The femoral vein is accessed below the inguinal ligament.

Technique

- For IJV and SCV sites, the distance between the intended cutaneous puncture site and the angle of Louis (manubriosternal junction) along the trajectory of the vein should be measured (Fig. 16.9). This estimates the appropriate length of catheter to insert (Figure 16.9):

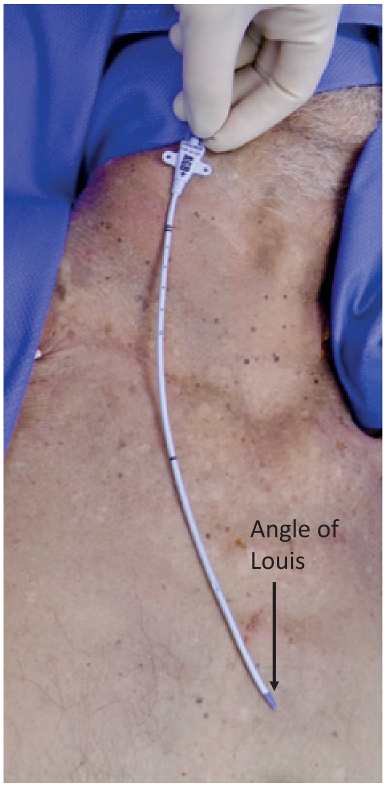


Figure 16.9 The length of catheter for insertion in the IJV or SCV can be estimated by measuring the distance between the intended puncture site and the angle of Louis.

  - ○ Right IJV – advance to approximately 15 cm
  - ○ Right SCV – advance to approximately 16 cm
  - ○ Left IJV – advance to approximately 17 cm
  - ○ Left SCV – advance to approximately 18 cm
  - ○ Femoral vein – advance to hub

- The CVC and dilators should then be flushed with saline.
- Lidocaine is injected with a 25-gauge needle over the intended puncture site to provide local anesthesia.
- An 18-gauge Seldinger needle is used to access the desired vessel, as described for the three sites noted previously.
- The operator should aspirate while advancing the needle. A rapid return of blood indicates venipuncture. Venous blood should be dark and nonpulsatile, although in shock states, the appearance and flow of the blood can be misleading. Advancing the needle can oppose the anterior and posterior walls of the vessel, collapsing the lumen and permitting the needle to pass through both walls of the vessel. For this reason, if no return of blood is obtained after appropriate depth of needle advancement, the needle should be withdrawn slowly with continued aspiration.
- Once the vein has been accessed, the needle should be stabilized in position with the nondominant hand, while the syringe is removed from the needle (Figure 16.10).

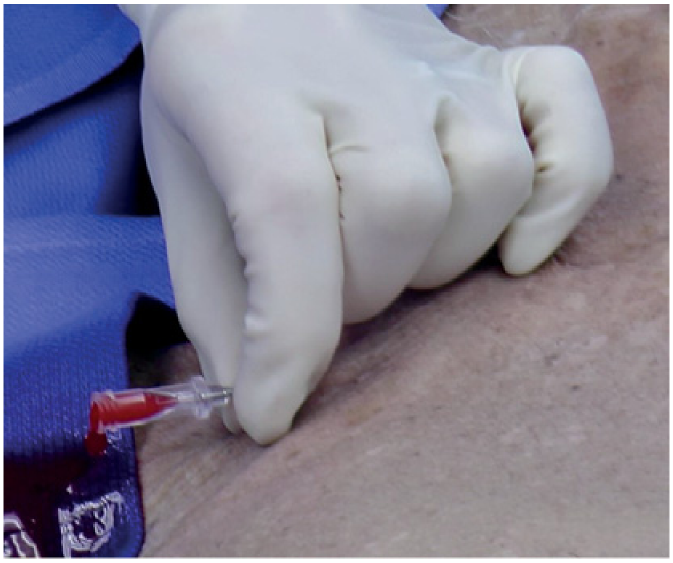


Figure 16.10 After the vein has been accessed, the needle is stabilized in position and the syringe is removed.

- The J-tip of the guidewire should then be inserted through the Seldinger needle into the vessel. The wire is then advanced approximately 15–20 cm. The operator maintains the guidewire with the nondominant hand throughout the remainder of the procedure. The needle is then removed (Figure 16.11).

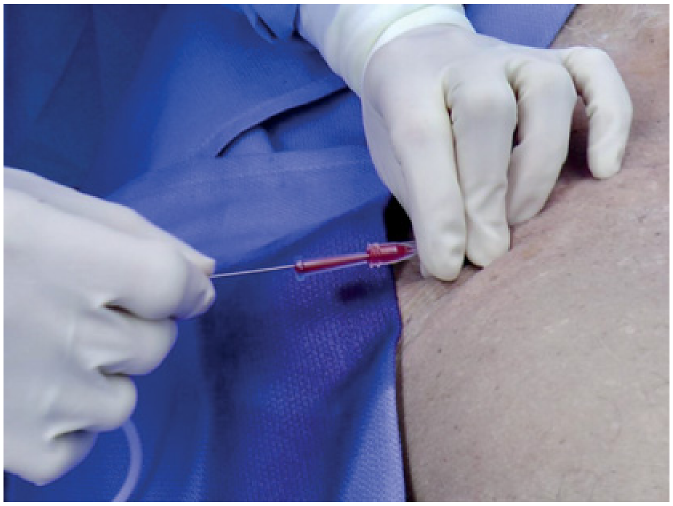


Figure 16.11 The guidewire is inserted through the needle.

- As an alternative to the Seldinger needle, an angiocatheter can be placed into the central vessel, similar to placement of a peripheral IV. The guidewire can then be placed through the angiocatheter. Some have advocated this approach as less likely to cause damage to the vessel, especially the posterior wall as the guidewire is introduced (Figure 16.12).

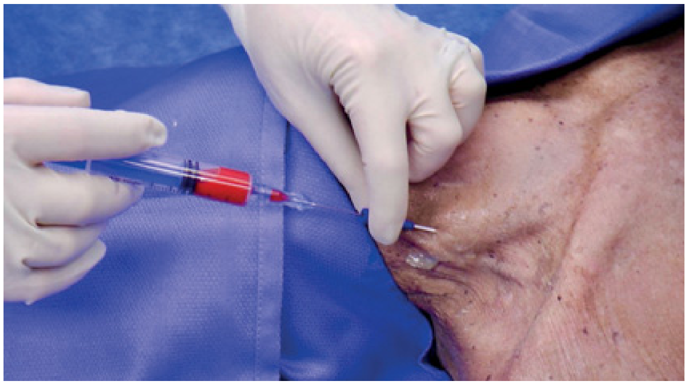


Figure 16.12 An angiocatheter is placed into the central vessel and the needle is withdrawn.

- If performing an ultrasound-guided IJV or femoral vein catheter, the ultrasound can be used to confirm placement of the guidewire in the vein in the longitudinal field. It is possible to insert the needle through the back wall of the vein inadvertently during access. If this happens, the needle, and subsequent guidewire, can enter the artery. Some institutions require a screenshot of this longitudinal view of the wire in the vein for quality assurance purposes (Figure 16.13).

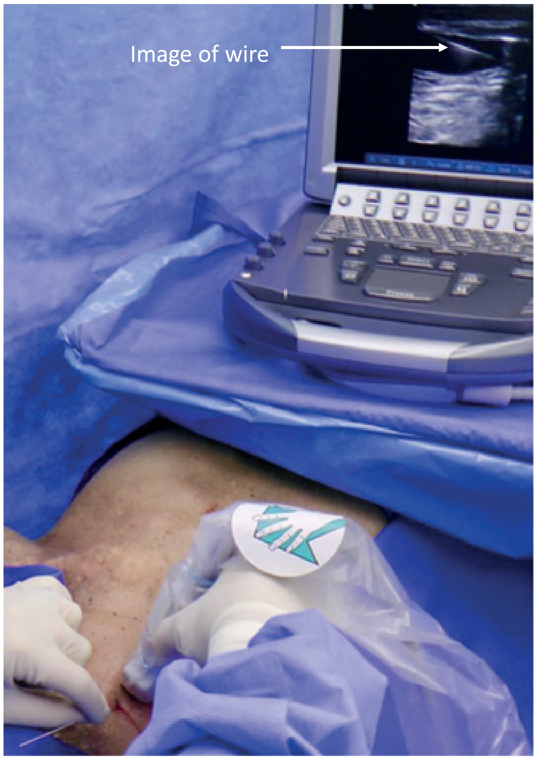


Figure 16.13 Ultrasound in the longitudinal plane is used for confirmation that the guidewire is in the vein.

- A #11 blade is then used to make a 5 mm stab incision adjacent to the guidewire. There should be no skin bridge between the guidewire and the stab incision (Figure 16.14).

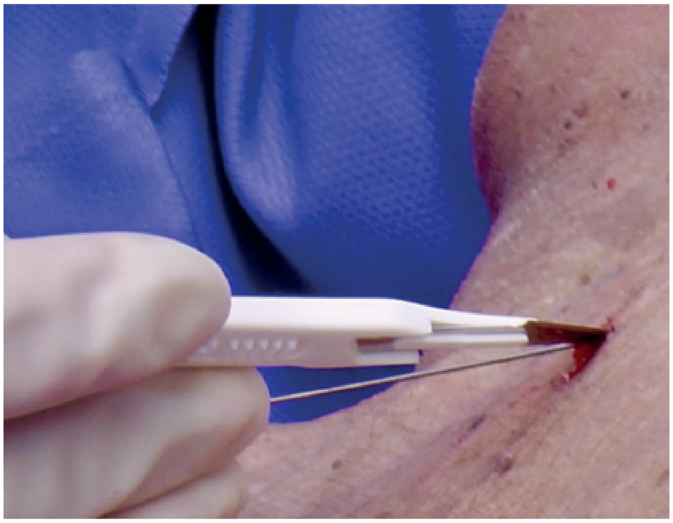


Figure 16.14 A stab incision is made adjacent to the guidewire.

- A dilator should then be advanced with the operator's dominant hand over the wire and into the vessel. The end of the guidewire is maintained by the nondominant hand while advancing the dilator. The dilator should not be advanced more than a few millimeters into the vein. This distance can be estimated based on the depth that was required for venipuncture. Between advances of the dilator, the wire should be advanced and retracted slightly within the dilator to confirm that no false passage developed. Pressure should be applied to the insertion site after removal of the dilator to prevent excessive blood loss. (Figure 16.15).

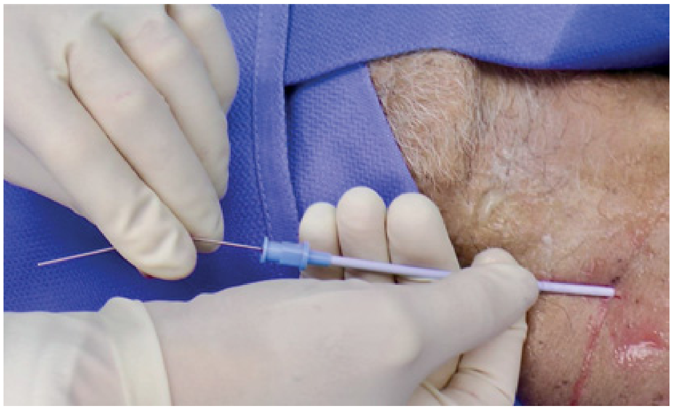


Figure 16.15 Dilation is performed over the guidewire for placement of a CVC in the IJV.

- The CVC is then advanced over the guidewire to the predetermined adequate depth. The guidewire should then be removed from the catheter (Figure 16.16).

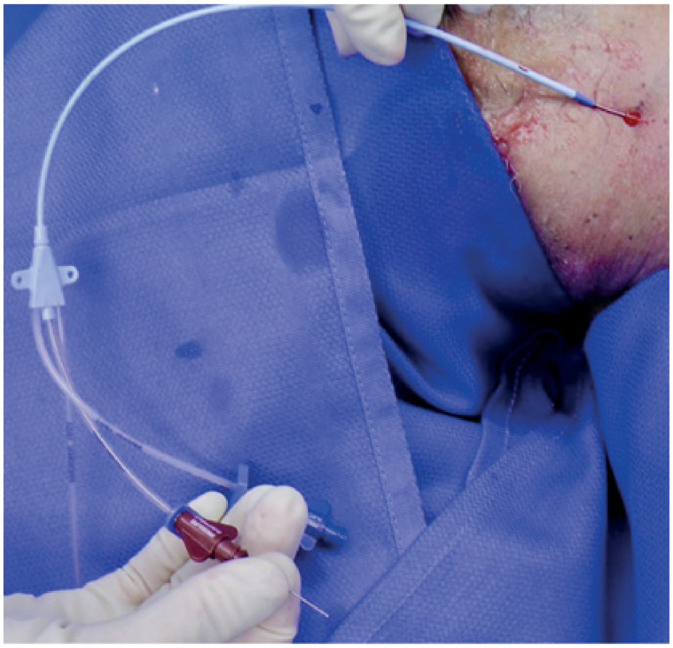


Figure 16.16 A triple lumen catheter is placed over the guidewire into the IJV.

- If the line requires more than one dilator, they are used successively, from smallest to largest. For single lumen CVCs, the dilator is loaded through the catheter, and the two are simultaneously inserted into the vessel over the wire, with the dilator and wire subsequently withdrawn. (Figure 16.17).
- A trace of blood should be drawn from each port with subsequent flushing of sterile saline to confirm function and to clear the line.

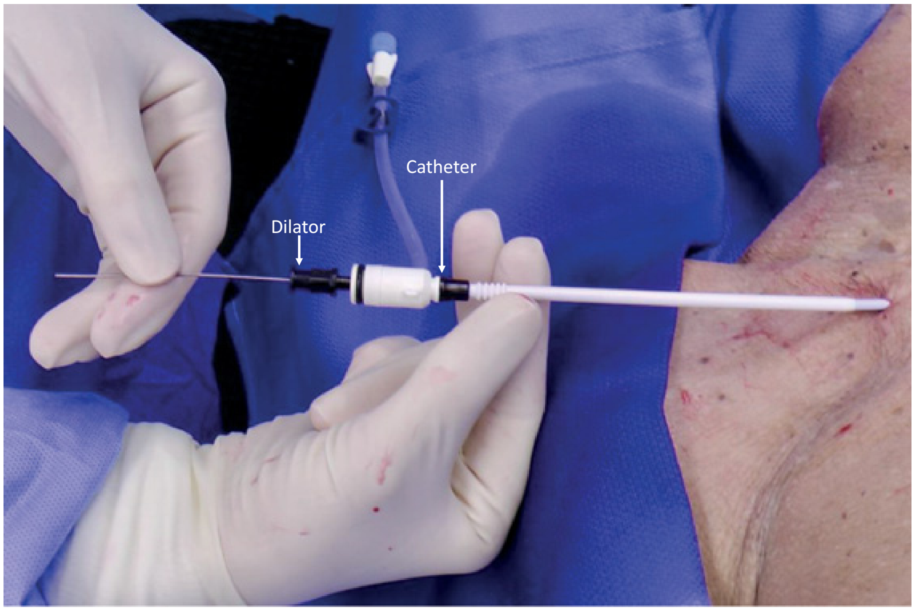


Figure 16.17 The dilator and catheter are simultaneously inserted into the vessel, and the dilator is subsequently withdrawn.

- The catheter is then secured to the skin with simple non-absorbable sutures. Chlorhexidine-impregnated dressings are recommended to protect the insertion site from infection. Lastly, a sterile dressing is applied (Figure 16.18).

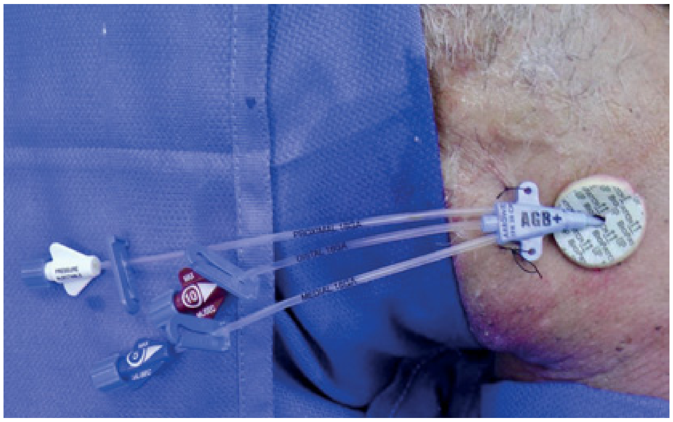


Figure 16.18 A chlorhexidine patch is placed around the catheter at the access site and caps are placed on each lumen of the triple lumen catheter.

- A portable chest X-ray should be ordered after placement of an IJV or SCV catheter. The chest X-ray has two purposes (Figure 16.19):

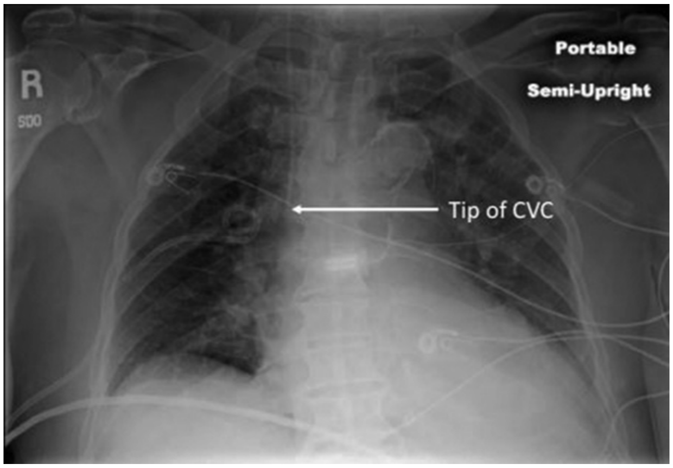


Figure 16.19 Chest X-ray demonstrating a triple lumen catheter with tip in correct position at the junction of the superior vena cava and right atrium.

    - It assesses the position of the tip of the catheter. The tip should ideally be located at the junction of the superior vena cava and right atrium. This is approximately 3 cm below the right tracheobronchial angle. Placement of the catheter in the right atrium risks cardiac perforation and tamponade.
    - It confirms there is no pneumothorax or hemothorax from needle puncture.

Catheter Removal

- Catheters should be evaluated daily for medical necessity. Catheters placed emergently, under suboptimal sterility, should be removed or replaced within 24 hours.
- To remove IJV or SCV lines, the patient should be placed in the Trendelenburg position, which decreases the risk of air embolism.
- The sterile dressing is removed, the sutures are cut, and the catheter is slowly retracted while applying pressure over the vein. Pressure should be held on the site for 10 min, and then hemostasis should be confirmed.
    - A sterile dressing can then be applied.

Complications

- Pneumothorax is a potential risk associated with the IJV and SCV sites. In patients with unilateral lung or chest pathology, it is advisable to access on the pathologic side to protect the normal lung.
- Hematoma formation and bleeding complications are increased in patients with a coagulopathy. In patients deemed to be at risk for bleeding complications, such as an INR >1.5, or platelet count <50,000, the SVC site is not recommended, as it is not compressible.
- Arterial cannulation – Puncture of the artery may lead to brisk bleeding/hematoma formation. If the dilator or catheter is inadvertently advanced into an artery, then placement of the line should be completed, and it should be connected to a pressure bag. Surgical or interventional arterial repair will be required promptly.
- Infection – If CVC infection is suspected, the line should be removed. Blood cultures should be obtained and antibiotics initiated.
- Air embolism is a potential complication during both catheter placement and removal. The use of the Trendelenburg position greatly decreases the risk of this complication.

Tips and Pitfalls

- For IJV or SCV placement, ensure the patient can tolerate Trendelenburg positioning prior to set up. Patients may require supplemental oxygen. Conscious patients can experience claustrophobia from the drape.
- The tip of catheter in IJV or SCV catheter should be in the superior vena cava, NOT in the right atrium, because of the risk of atrial perforation and cardiac tamponade!
- Sites with overlying cellulitis/infection or gross anatomical abnormalities should be avoided.
- Pneumothorax and inadvertent arterial cannulation are both less likely with ultrasound guidance.
- Whenever possible, it is recommended to check for compressibility of the femoral or IJV prior to attempting access. Rarely, patients may have a deep venous thrombosis, which will preclude line placement.
- Within the CVC kit, there is often a small sterile drape that may be placed over the ultrasound machine controls and allows the sterile operator to touch the controls.

- Consider using hemostats to clip the ultrasound probe to the sterile field to avoid contaminating or damaging the probe.
- The femoral vein should not be punctured above the inguinal ligament, as this is the external iliac vein. This is a non-compressible vessel, which increases the likelihood of a retroperitoneal hematoma after puncture or line removal.
- In patients with small vessels or severe volume depletion causing collapsible vessels, a micropuncture kit may be utilized to access the vessel. The steps for accessing the vessel are the same, although the dilator and guidewire will be much smaller. After the small dilator is removed, the larger dilator can be placed and subsequently the catheter, all facilitated over the smaller guidewire.
- Patients should be on telemetry during placement. If any ectopy occurs on the monitor, the wire should be withdrawn until the ectopy ceases. Arrhythmias after catheter placement indicate catheter tip irritation of the right atrial wall (the catheter has been advanced too far).
- After CVC placement, a saline flush can be pushed via one of the central line ports while visualizing the heart with ultrasound via the four chamber or apical view. Proper placement of the distal tip of the catheter is confirmed when the saline is visualized swirling in the right atrium within 2 seconds of saline administration, also known as the rapid atrial swirl sign.

Chapter

17

Intraosseous Access Techniques

Angelica Loza-Gomez and Aaron Strumwasser

Introduction

- Intraosseous (IO) infusion is based on the principle that medullary veins of long bones remain patent during shock and hypovolemia.
- Emergent medical and traumatic conditions may make traditional IV access difficult in patients secondary to obesity, edema, burns, or history of IV drug abuse.
- The success rates of IO placement with a battery-powered device are higher than 95% and normally achieved in less than one minute.
- IO access allows for fluid resuscitation, blood product delivery, and life-saving drug administration, with similar efficacy to IV access. Peripheral blood sampling can be performed via IO cannulation.
- IO access provides a route for all Advanced Cardiac Life Support (ACLS) fluids and drugs, at the same doses prescribed for traditional IV access. However, adenosine, antibiotics, and phenytoin require adjusted dosing for IO administration.
- Infusion rate under pressure with infusion pump, pressure bag, or manual pressure range from 1,000 ml/hr to 5,000 ml/hr, but will vary among patients and anatomical sites. In general, gravity alone will not generate an adequate flow rate for resuscitation.
- IO catheters should be replaced with a venous line as soon as possible. Catheters that stay in place beyond 24 hours are associated with an increased risk of osteomyelitis.

Indications

- IO access is useful in resuscitating the severely injured or critically ill patient when peripheral access is unobtainable.
- IO access may be an acceptable first attempt venous access in patients in full cardiopulmonary arrest or severe shock. In these cases, IO cannulation and peripheral venous access may be attempted simultaneously.
- IO access may be used for drug, fluid, or blood product administration, and some blood draw samples.

Contraindications

- IO placement is contraindicated in the presence of extremity fractures. A fractured bone leads to direct extravasation of fluids and medications into the surrounding tissues.
- Infection at a bony insertion site should prompt the provider to choose a different site of insertion in order to avoid spreading sepsis or osteitis.
- In general, IO access should be avoided in severe osteoporosis and genetic or acquired bone diseases.
- Extremity sites with severe soft tissue trauma, burns, or compartment syndrome should be avoided.

Equipment

- IO catheters come in two forms: (1) manual needles and (2) battery-powered driver.
- The choice of device (manual or battery-powered) is based on patient age, bony site, institutional availability, and physician preference.
    - In infants under one year of age, consider manual needles or battery-powered devices.
    - In children one year of age or older, adolescents, and adults, consider a battery-powered device.
- The needle size depends on the age and weight of patient, along with the commercially available kits.
- The needles are color-coded according to age and weight.

Anatomic Sites and Patient Preparation

Sternum

- Ensure the IO device chosen is intended for sternal placement.
- Patients are positioned supine.
- The sternal notch is palpated and a site selected for insertion should be 2 cm distal, within the manubrium. Some manufacturers provide a device-specific guide for sternal placement to assist with site identification and cannulation (Figure 17.1).

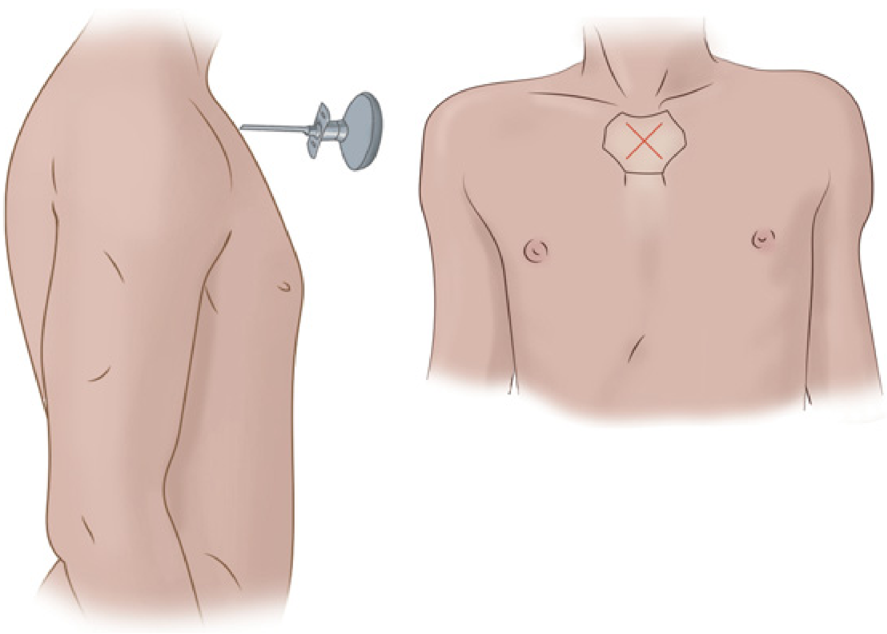


Figure 17.1 Sternal insertion site. The manual insertion site is 2 cm distal to the sternal notch, within the manubrium.

Proximal Humerus

- The patient should be supine, with the elbow adducted and arm internally rotated across the torso. When positioned correctly the palm overlies the umbilicus. This will minimize the likelihood of brachial plexus injury.
- The humerus is then palpated and the greater tuberosity identified as the insertion point, 1 to 2 cm above the surgical neck and lateral to the intertubercular groove (also known as the bicipital groove) (Figure 17.2).

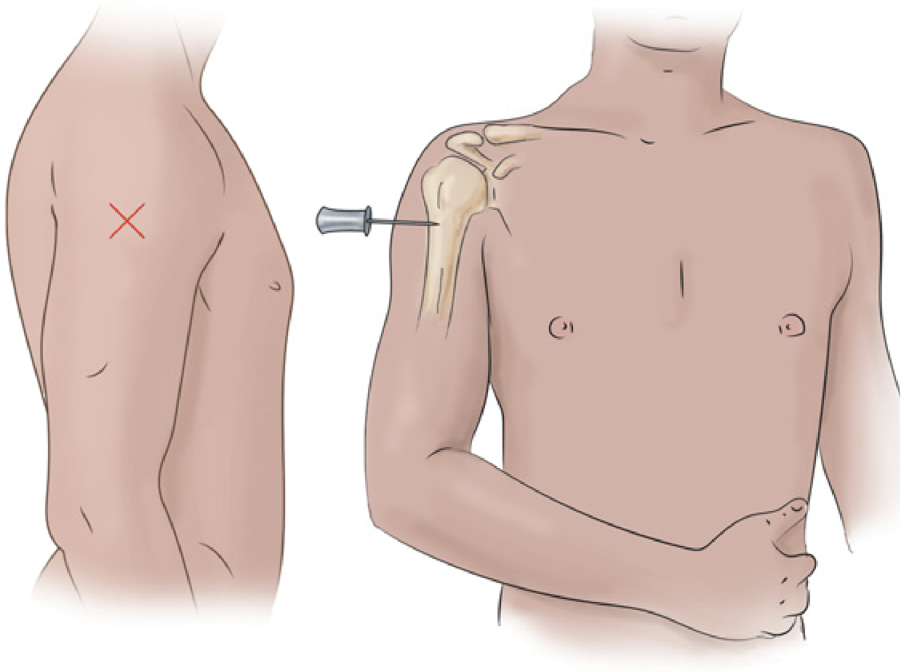


Figure 17.2 Humerus insertion site. The greater tuberosity is identified, about 2–3 cm inferior to the acromion process.

- Insert and aim the needle set at a 45-degree angle downward. It might be useful to aim the needle tip toward the inferior lateral border of the scapula.
- Gently drill approximately 2 cm or just before the hub overlies the skin in adults. For children, stop when you feel a "give" or a "pop."
- This anatomical location should be cannulated preferably with the battery-powered device.

Proximal Tibia

- The patient should be supine with the hip extended and the knee slightly flexed, if possible.
- Assistants should stabilize the lower leg manually and the knee, supported by towel rolls.
- The tibial tuberosity is palpated just below the knee.
- The insertion site is two fingerbreadths (2 cm) distal to the tibial tuberosity and two fingerbreadths (2 cm) medial on the flat portion of the tibia.
- Aim the needle set 90 degrees to the flat surface of the tibia (Figure 17.3).

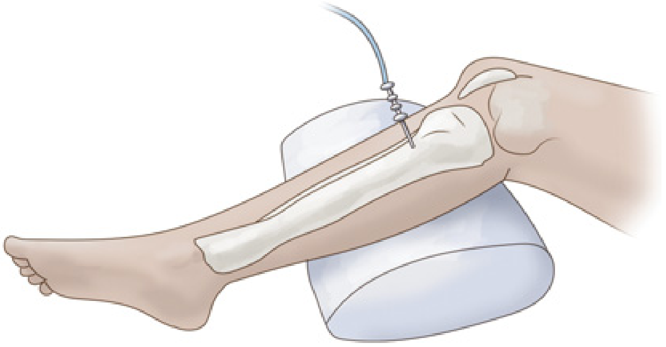


Figure 17.3 Proximal tibia insertion site. The insertion site is 2 cm distal and 2 cm medial to the tibial tuberosity.

Distal Tibia

- Insertion site for adults is approximately 3 cm proximal to the medial malleolus (Figure 17.4).
- For small children and infants, insertion site is 1–2 cm proximal to the most prominent portion of the medial malleolus.
- Palpate the anterior and posterior borders of the tibia and identify the flat portion of the tibial bone.
- The needle set should be aimed 90 degrees perpendicular to the surface of the bone.

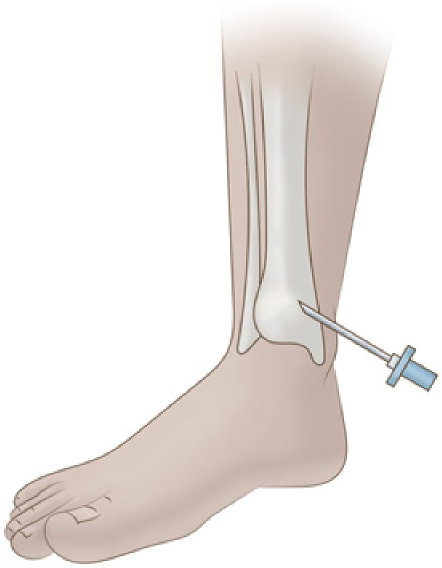


Figure 17.4 Distal tibia insertion site. The insertion site is 2–3 cm proximal to the medial malleolus.

Distal Tibia Intraosseous Catheterization Procedure

Battery Powered Driver

- Position the patient as described previously.
- Cleanse the insertion site with antiseptic as per institution protocol.
- In the awake patient inject 3-5 cc of 1% lidocaine (preservative free and epinephrine free) at the insertion site and adjacent to the periosteum.
- Check the equipment, needle size, and battery (Figure 17.5).

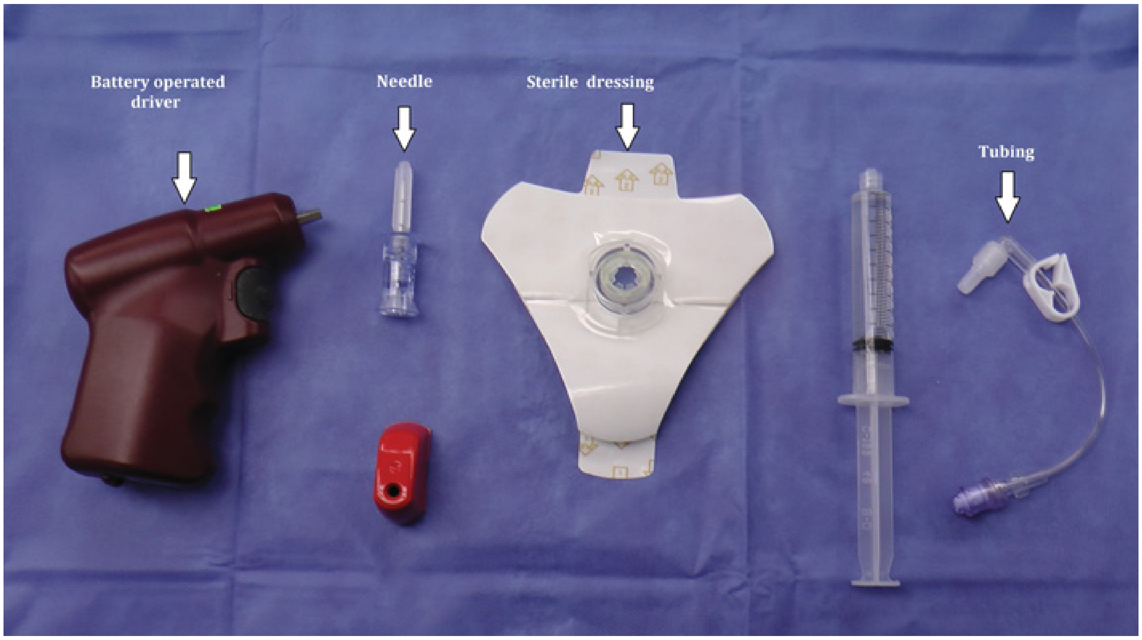


Figure 17.5 Battery operated driver kit and components.

- Remove the safety cap and position the needle perpendicular to the bone (Figure 17.6).
- Squeeze the trigger and use light driving pressure to penetrate bone, ensuring the hub overlies the skin.
- When there is a loss of resistance, release the trigger, wait for the driver to stop spinning, and then hold the hub in place pulling the driver straight off needle set (Figure 17.7).

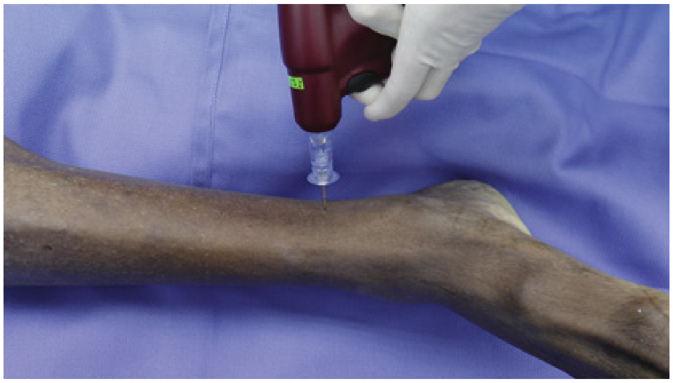


Figure 17.6 Position the needle perpendicular to the distal tibia bone and squeeze the trigger of the battery-operated driver.

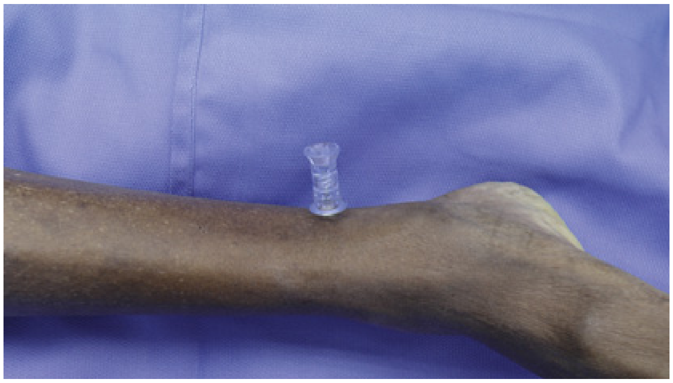


Figure 17.7 The needle is advanced into the bone with the hub just above the skin.

- Unscrew the needle stylet, rotating it counterclockwise (Figure 17.8).

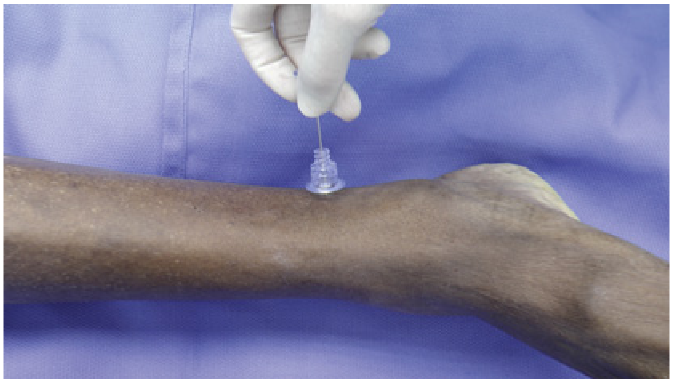


Figure 17.8 Remove the inner stylet from the catheter.

- Connect IV tubing and aspirate marrow to confirm correct placement (Figure 17.10).
- Flush with 5-10 ml of normal saline for adults and 2–5 ml for children.
- Monitor infusion and site frequently for infiltration.

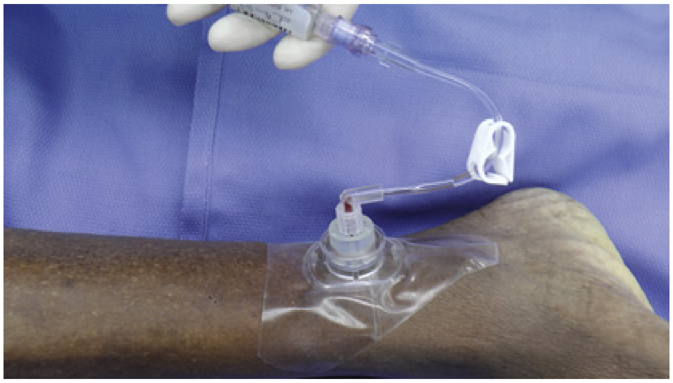


Figure 17.10 IV tubing is connected to the catheter and bone marrow is aspirated.

- Secure the hub and needle with a commercially available adhesive pad (Figure 17.9).

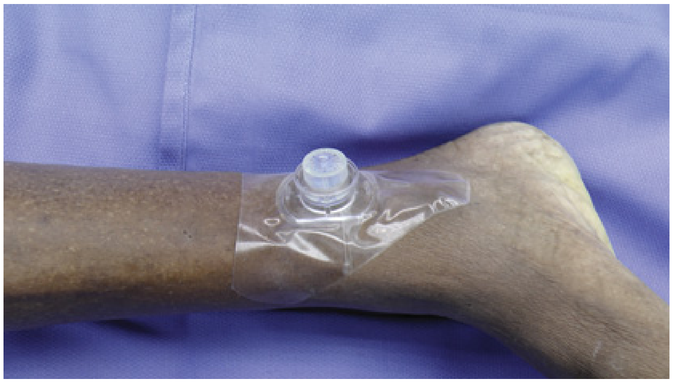


Figure 17.9 Secure with commercial adhesive pad.

Proximal Tibia Intraosseous Catheterization Procedure

Manual Needle

- Position the patient as described previously.
- Cleanse insertion site with antiseptic per hospital protocol. Infiltrate with local anesthetic as described previously.
- Select an appropriately sized manual needle. (Figure 17.11 A,B)

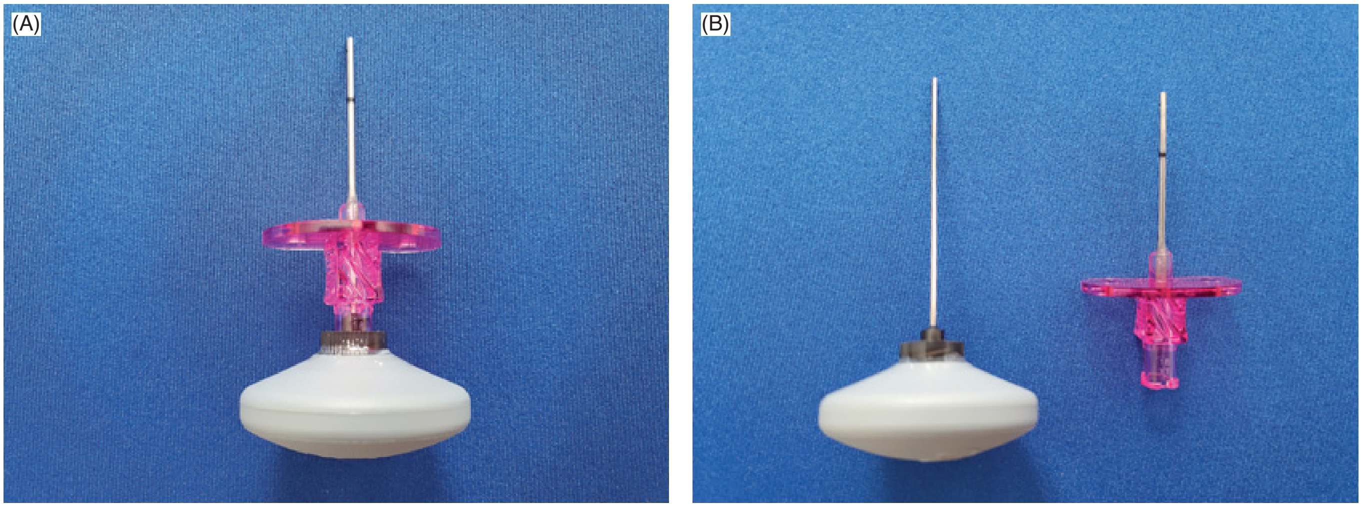


Figure 17.11 A, B Manual needle ready for insertion (A). Manual needle with inner cannula removed (B).

- Apply a twisting motion, directing the IO needle perpendicular and slightly away from the knee joint (10 degrees from perpendicular) (Figure 17.12).
- When the needle penetrates through the cortex of bone into the marrow, a sudden "give" or unimpeded resistance is felt.
- Unscrew the needle cap and remove the inner cannula as described previously.
- Connect IV tubing and confirm correct needle placement by aspiration of marrow as described previously.
- Flush the catheter with 5–10 ml of normal saline for adults and 2–5 ml for children.

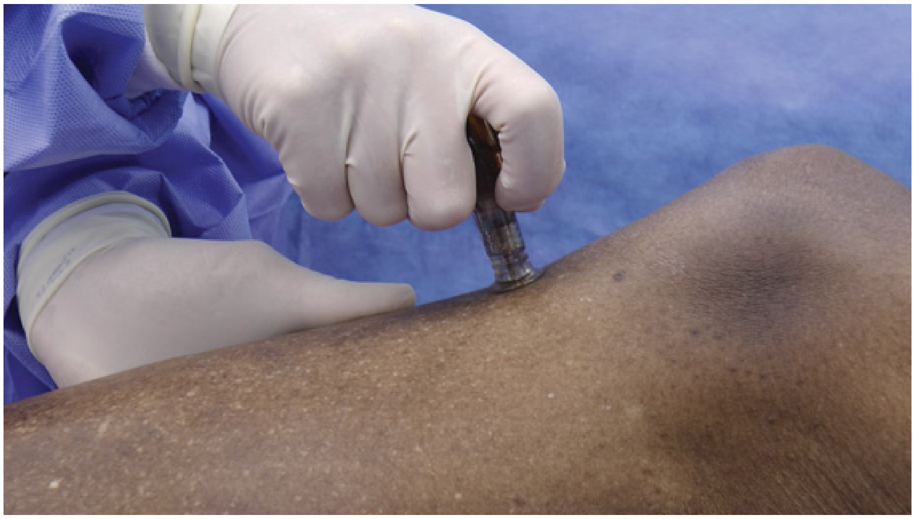


Figure 17.12 A twisting motion directs the manual needle into the cortex.

Sternal Intraosseous Catheterization Procedure

Manual Bone Probe Device

- Position the patient and palpate the insertion site as described previously.
- Use the adhesive sternal locator to confirm alignment with the sternal notch and manubrium. Bone probe needles should reside centrally over the manubrium. (Figure 17.13, Figure 17.14)

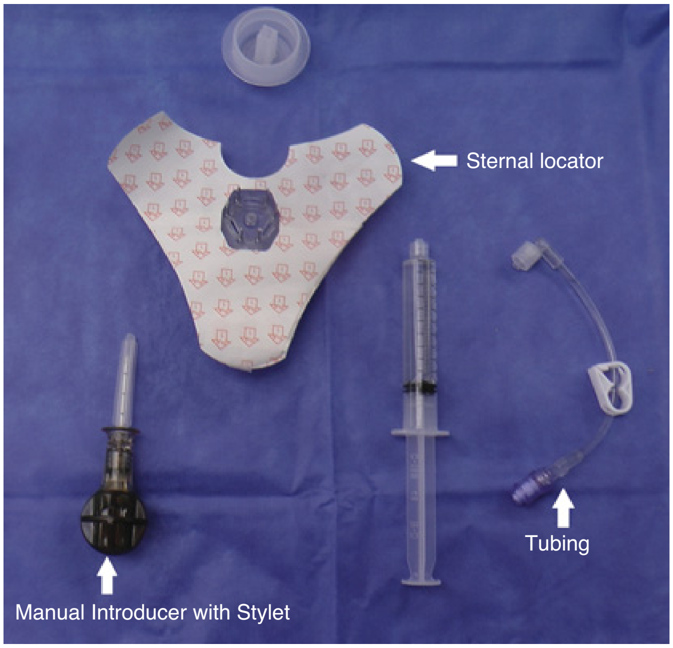


Figure 17.13 Sternal manual bone probe kit and components.

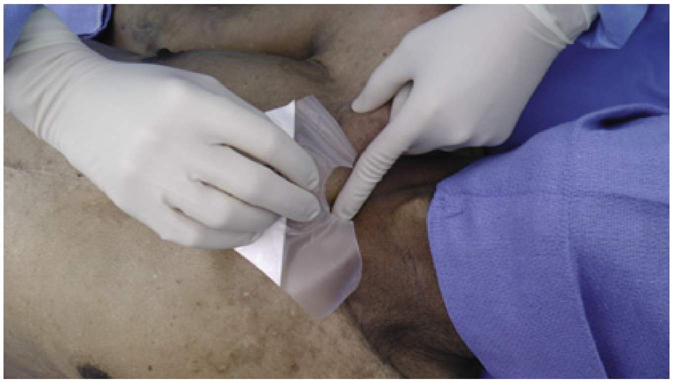


Figure 17.14 Align the sternal locator over the manubrium.

- Remove the safety cap and introducer. Align the sternal locator with the manubrium (Figure 17.15).

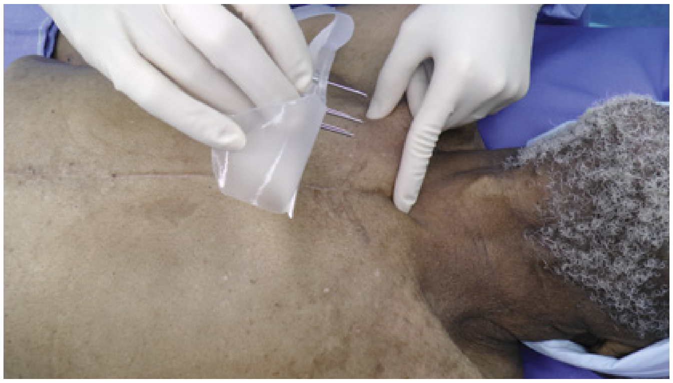


Figure 17.15 Insert the probe needles over the manubrium.

- Apply pressure to the probe needles perpendicular to the manubrium until a “pop” is heard (Figure 17.16).

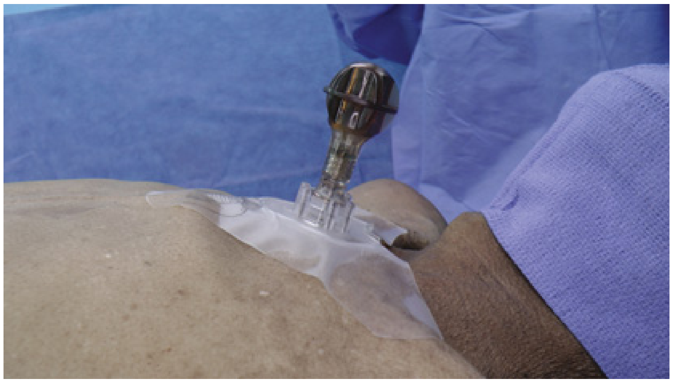


Figure 17.16 Insert the manual handle with stylet into the cortex.

- Apply manual introducer with stylet in a twisting motion into the center hub of the sternal locator. Twist in a perpendicular fashion until a “pop” is heard (Figure 17.17).

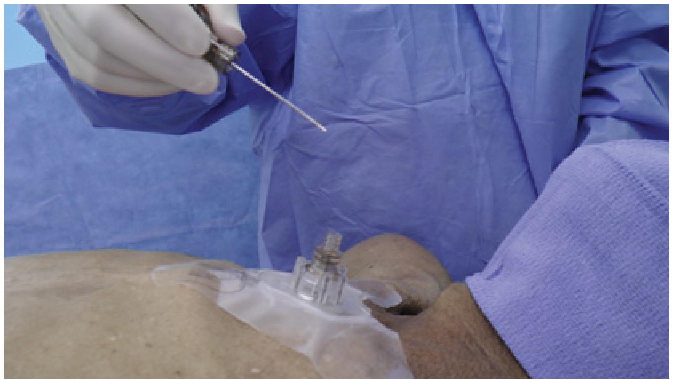


Figure 17.17 Remove the inner stylet from the catheter.

- Unscrew the introducer and brown cap from the IO catheter by twisting in a counterclockwise fashion.
- Connect IV tubing and confirm correct placement by aspiration of bone marrow (Figure 17.18).

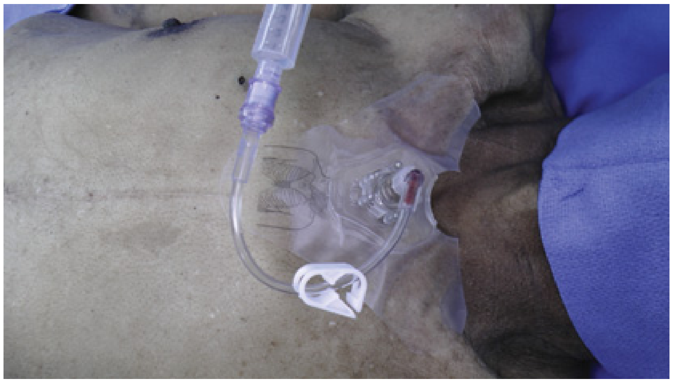


Figure 17.18 IV tubing is connected to the catheter and marrow is aspirated.

- Flush with 5–10 ml of normal saline.

Complications

- IO cannulation is considered to be relatively safe, with a rate of serious complications of less than 1%.
- IO use should be limited to a few hours until IV access is achieved, to minimize the risks associated with prolonged use. IO catheters should be removed within a maximum of 24 hours.
- Compartment syndrome from extravasation of fluid is a common complication.
- Other complications include needle displacement, skin necrosis, osteomyelitis, and subcutaneous abscess. Fat embolism is a very rare complication.
- Sternal IO cannulation with an inappropriately long needle may result in injury to the mediastinal vessels or the heart.

Tips and Pitfalls

- A battery-powered device is preferable in both pediatric and adult patients.
- A correctly placed IO catheter includes the following: (1) loss of resistance on entering the marrow cavity, (2) stands firmly on its own within the bone, (3) aspiration of bone marrow, and (4) administration of normal saline without tissue swelling or resistance.
- Avoid needle misplacement by securing the IO with a device-specific adhesive tape and tubing secured with at least two omental tapes on the limb where the needle is inserted.
- A wrong-size needle can cause serious injury and complications. Choose the size of the needle carefully, on the basis of weight and age.
- If extravasation occurs with an IO, evaluate and monitor for compartment syndrome.
- Bone marrow cannot always be aspirated, but normal saline should always flush through the IO without surrounding tissue swelling.

Chapter

18

Cricothyroidotomy

Morgan Schellenberg and Demetrios Demetriades

General Principles

- When attempts at orotracheal intubation or airway rescue techniques (e.g., laryngeal mask airway) have failed in a patient who cannot oxygenate or ventilate, cricothyroidotomy is the emergency surgical airway of choice. It can be performed open or percutaneously. The approach should be dictated by the proceduralist's preference and experience.
- In pediatric patients (<12 years), cricothyroidotomy is relatively contraindicated because the risk of long-term complications, such as stenosis, are especially high. Transtracheal needle jet ventilation should be considered in these patients, as a temporary oxygenation and ventilation alternative, while preparing for a more definitive airway management.
- The cricothyroid membrane is identified externally as the soft space immediately below the thyroid cartilage (Figure 18.1).

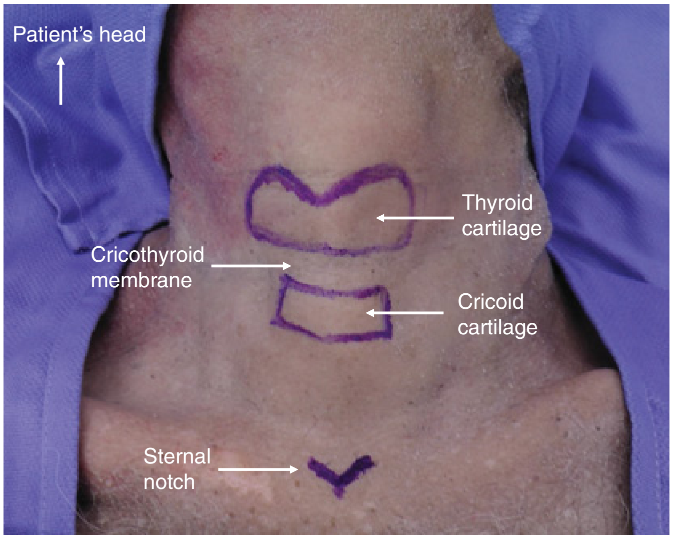


Figure 18.1 Surface anatomy for cricothyroidotomy.

- In patients with obscured anatomy (e.g., body habitus, neck trauma), the four-finger technique is a useful method of rapidly estimating the surface landmark for the cricothyroid membrane (Figure 18.2)

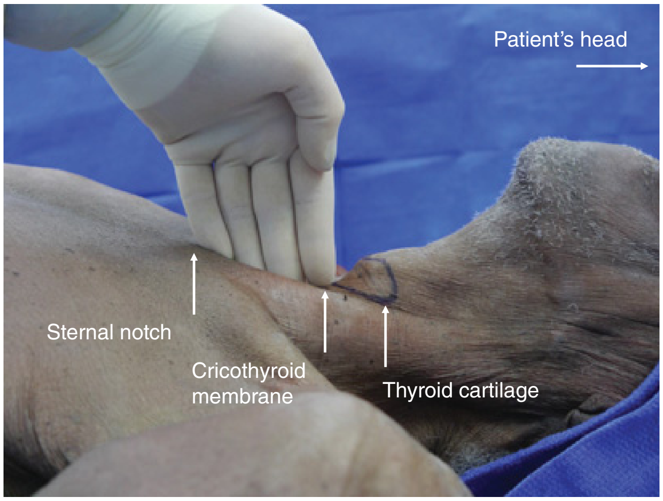


Figure 18.2 The four-finger technique for external landmarking of the cricothyroid membrane. With the physician's palm extended, the tip of the small finger is placed in the sternal notch. In this position, the tip of the index finger points at the cricothyroid membrane in the midline.

- With the proceduralist's four fingers extended next to one another, the small finger is placed onto the patient's sternal notch. The tip of the index finger approximates the location of the cricothyroid membrane in this position.
- It is not necessary to convert a cricothyroidotomy to a tracheostomy after patient stabilization.

Special Surgical Instruments

- At a minimum, a scalpel and an endotracheal or tracheostomy tube are required to perform an open cricothyroidotomy. Optimally, a tracheal hook, bougie, Senn retractors, Kelly clamp, Metzenbaum scissors, and forceps should also be available (Figure 18.3)).

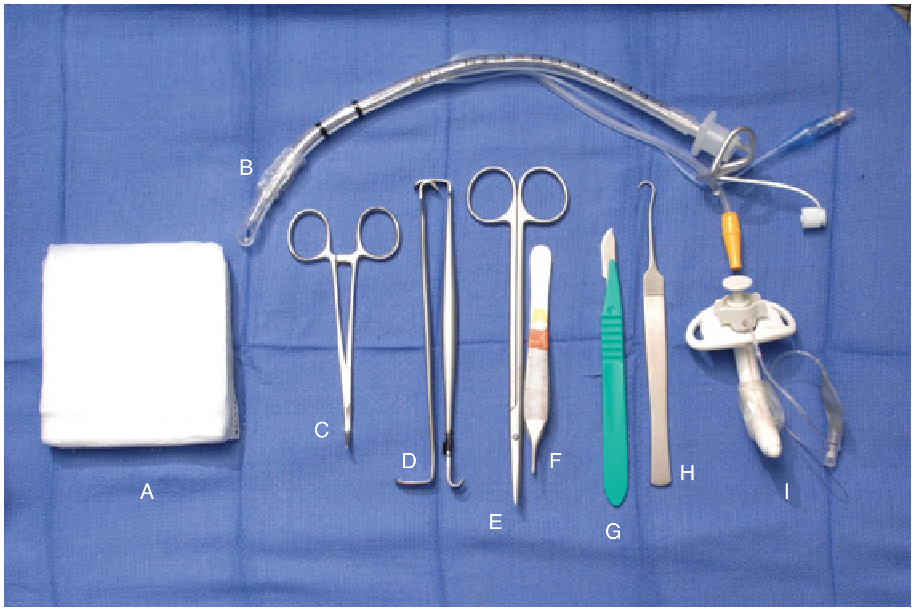


Figure 18.3 Equipment for open cricothyroidotomy. Open cricothyroidotomy equipment. (A), 4×4 gauze. (B), endotracheal tube. (C), Kelly clamp. (D), Senn retractors. (E), Metzenbaum scissors. (F), forceps. (G), scalpel. (H), tracheal hook. (I), tracheostomy tube.

- There are several commercially available percutaneous cricothyroidotomy sets (Figure 18.4).

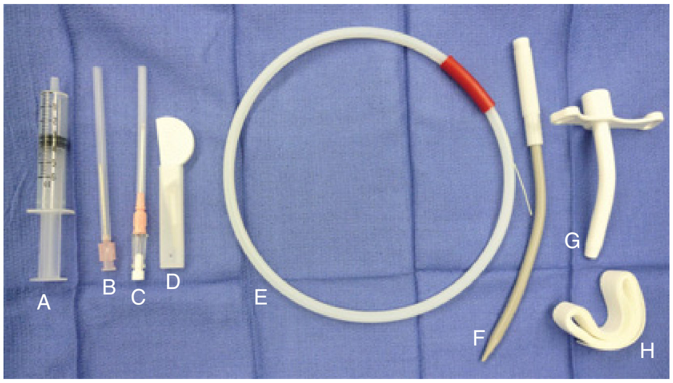


Figure 18.4 Equipment for percutaneous cricothyroidotomy. Percutaneous cricothyroidotomy kit. A, syringe. B, needle. C, angiocatheter. D, scalpel. E, guidewire. F, dilator. G, cricothyroidotomy tube. H, cricothyroidotomy tube ties.

- If percutaneous cricothyroidotomy is performed, the equipment for open cricothyroidotomy should be present bedside in case conversion is required.
- Suction, lighting, bag valve mask, an end-tidal CO_2 detector, and endotracheal/tracheostomy tubes of various sizes should be immediately available.

Positioning

- If cervical spine precautions must be maintained, cricothyroidotomy can be performed with the neck in neutral position. If the cervical spine has been cleared, neck extension and placement of a shoulder roll will help bring the airway into an anterior position, thereby facilitating cricothyroidotomy (Figure 18.5).

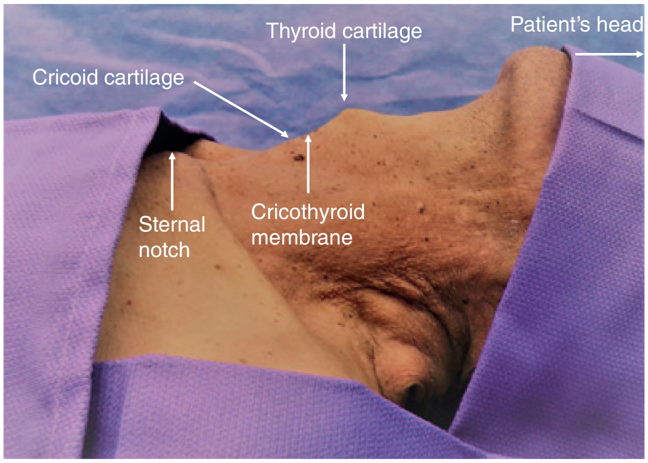


Figure 18.5 Patient positioning for cricothyroidotomy. If the cervical spine has been cleared, neck extension and placement of a shoulder roll will help bring the airway into an anterior position, thereby facilitating cricothyroidotomy. If cervical spine precautions must be maintained, cricothyroidotomy can be performed with the neck in neutral position.

Open Cricothyroidotomy

Surgical Anatomy

- The cricothyroid membrane is located in the midline anteriorly, between the thyroid cartilage above and the cricoid cartilage below (Figure 18.6A).
- Laterally, it is partially covered by the paired cricothyroid muscles (Figure 18.6B).
- The uncovered, medial portion of the cricothyroid membrane is the target for cricothyroidotomy.

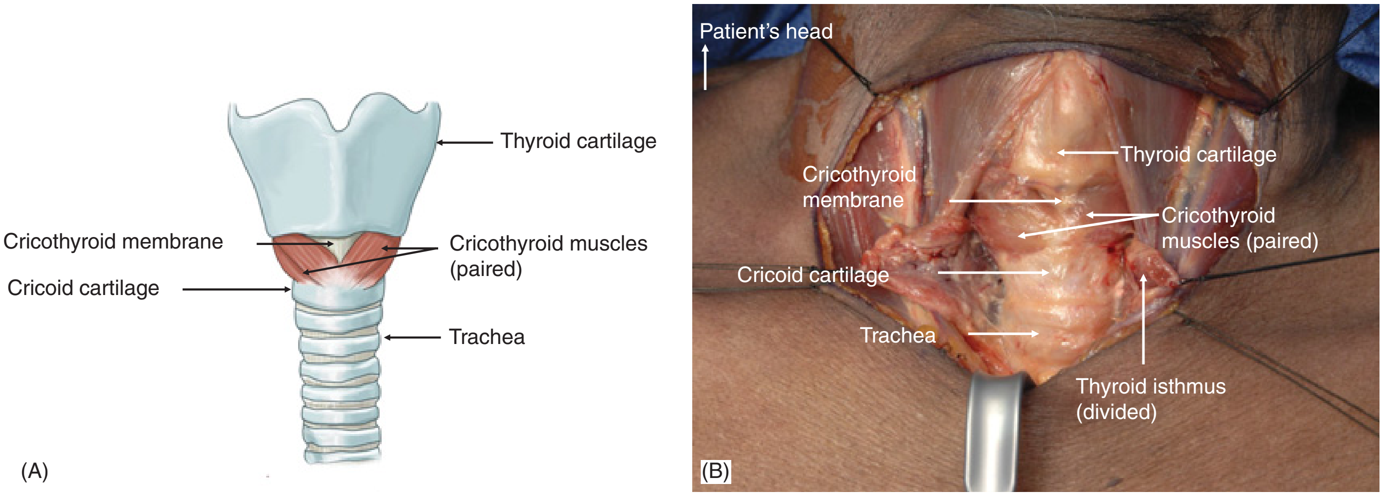

Thyroid cartilage
Cricothyroid membrane
Cricothyroid muscles (paired)
Cricoid cartilage
Trachea
(A)
Patient's head
Thyroid cartilage
Cricothyroid membrane
Cricothyroid muscles (paired)
Cricoid cartilage
Trachea
Thyroid isthmus (divided)
(B)

Figure 18.6 A,B Anatomy of the larynx. The cricothyroid membrane, partially covered by the paired cricothyroid muscles, is the target for cricothyroidotomy. The trachea begins caudal to the cricoid cartilage. The thyroid gland isthmus overlies the tracheal origin.

Incision

- A vertical incision of approximately 3 cm in length in the midline of the neck is preferred, centered over the cricothyroid membrane (Figure 18.7 A,B).
- A transverse incision may damage the bilateral anterior jugular veins and result in bleeding, obscuring visualization, and complicating the procedure. In experienced hands, a transverse incision is an acceptable option.

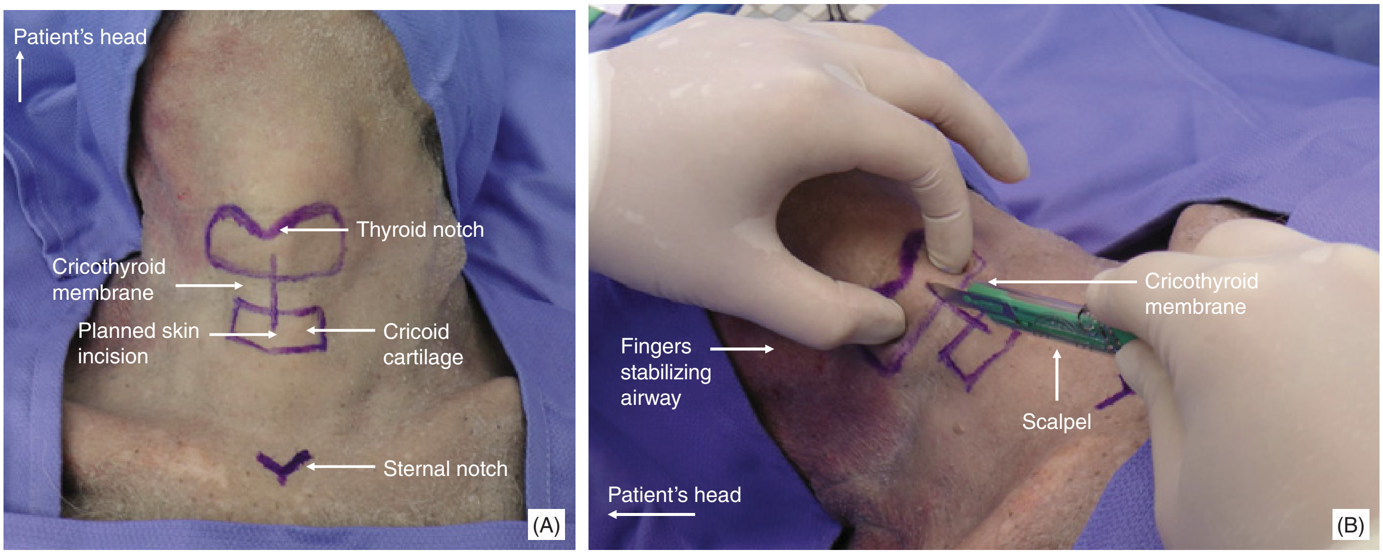

Patient's head
Thyroid notch
Cricothyroid membrane
Planned skin incision
Cricoid cartilage
Sternal notch
(A)
Cricothyroid membrane
Fingers stabilizing airway
Scalpel
Patient's head
(B)

Figure 18.7 A,B Skin incision for open cricothyroidotomy. The skin incision for open cricothyroidotomy is planned in the midline of the anterior neck, centered over the cricothyroid membrane (A). The incision is performed in a vertical orientation over a length of approximately 3 cm to provide adequate exposure of the underlying cricothyroid membrane. The scalpel is used to come through the skin and subcutaneous fat (B).

Procedure

- After the skin is incised, locate the cricothyroid membrane (Figure 18.8).
- With the scalpel, divide the cricothyroid membrane transversely. Extend the incision laterally approximately 1 cm to each side (Figure 18.9 A,B).

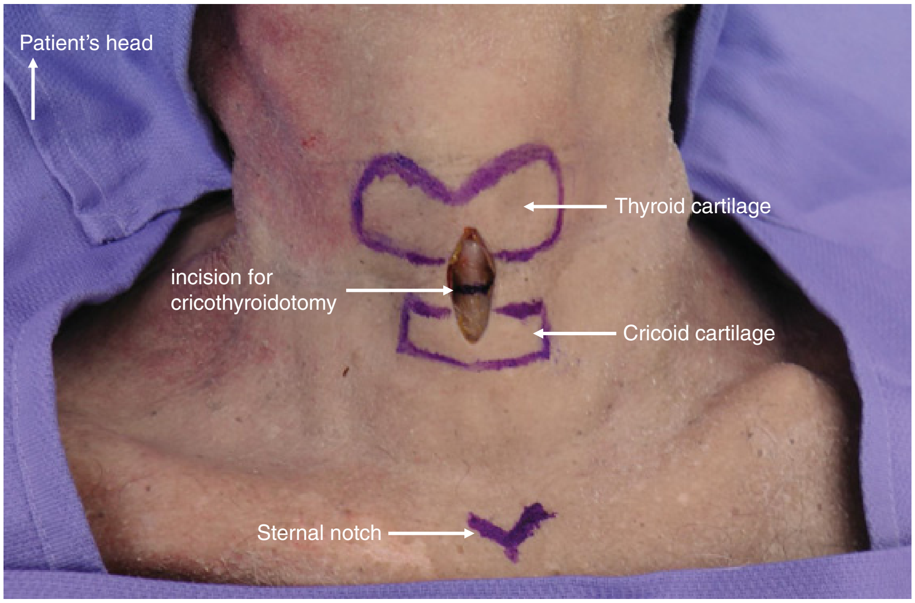

Patient's head
Thyroid cartilage
incision for cricothyroidotomy
Cricoid cartilage
Sternal notch

Figure 18.8 Exposure of the cricothyroid membrane. After the skin incision, locate the cricothyroid membrane within the incision as the soft depression between the thyroid and cricoid cartilages.

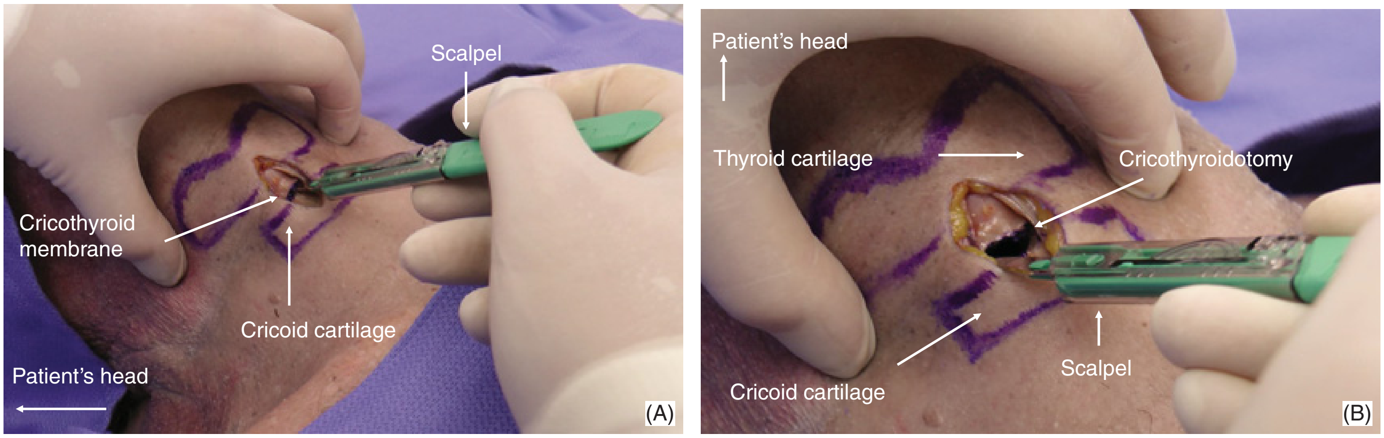

Scalpel
Cricothyroid membrane
Cricoid cartilage
Patient's head
(A)
Patient's head
Thyroid cartilage
Cricothyroidotomy
Cricoid cartilage
Scalpel
(B)

Figure 18.9 A,B Incision in the cricothyroid membrane. Use the scalpel to divide the cricothyroid membrane in a transverse orientation (A). Extend the cricothyroidotomy to a length of approximately 2 cm in order for it to safely accommodate an endotracheal, tracheostomy, or cricothyroidotomy tube (B).

- Insertion of the tracheal hook into the superior aspect of the cricothyroidotomy with upward retraction will immobilize the airway anteriorly and keep the cricothyroidotomy open (Figure 18.10).

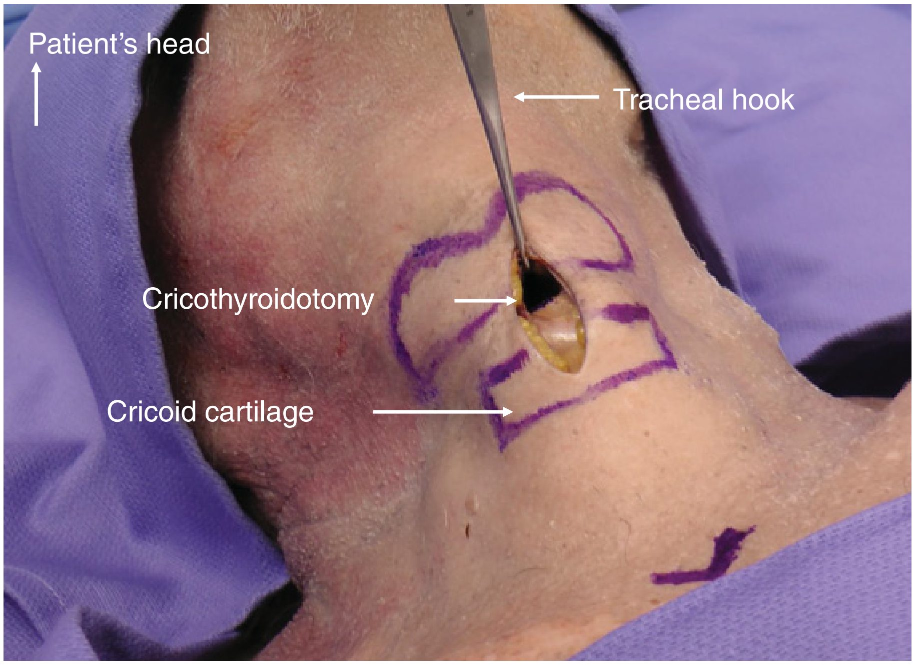

Patient's head
Tracheal hook
Cricothyroidotomy
Cricoid cartilage

Figure 18.10 Use of a tracheal hook as an adjunct. A tracheal hook can beinserted into the superior aspect of the cricothyroidotomy and anchored intothe thyroid cartilage to provide upward and cephalad retraction. This serves toimmobilize the airway and keep the cricothyroidotomy open, therebyfacilitating tube insertion.

- A tracheostomy or endotracheal tube is inserted through the cricothyroid incision (Figure 18.11).

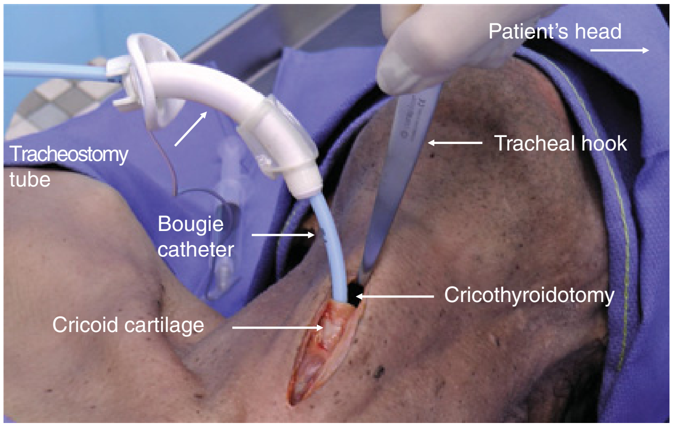

Patient's head
Tracheostomy tube
Tracheal hook
Bougie catheter
Cricothyroidotomy
Cricoid cartilage

Figure 18.11 Use of a bougie catheter as an adjunct. After performing the cricothyroidotomy, a bougie catheter can be passed into the airway toward the carina. This provides a helpful adjunct to facilitate tube insertion.

- A bougie catheter can be used to facilitate the insertion of the endotracheal or tracheostomy tube through the cricothyroidotomy. The endotracheal or tracheostomy tube is loaded over the bougie and inserted into the airway (Figure 18.12 A,B).

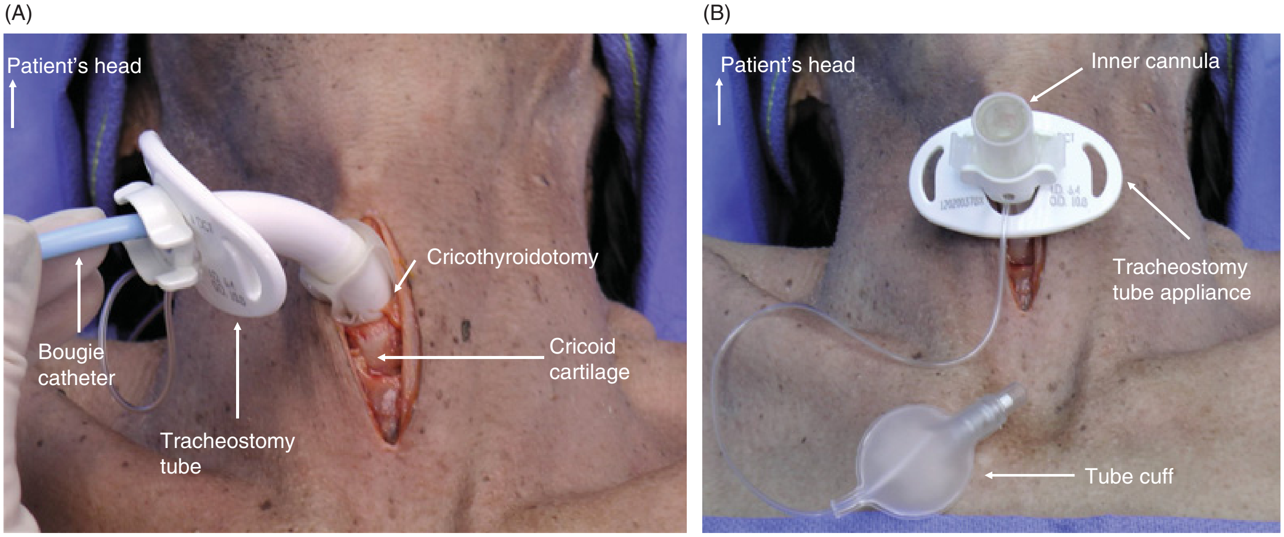

(A)
Patient's head
Cricothyroidotomy
Cricoid cartilage
Bougie catheter
Tracheostomy tube
(B)
Patient's head
Inner cannula
Tracheostomy tube appliance
Tube cuff

Figure 18.12 A,B Insertion of the tracheostomy tube. The tracheostomy tube is loaded over the bougie catheter and passed into the airway (A). Once the tube is situated in the airway, the bougie can be removed and exchanged for the inner cannula of the tracheostomy appliance. The tube cuff is then inflated (B).

- The bougie is removed, the inner cannula of the tracheostomy tube is inserted, and the tube cuff is inflated with approximately 10 ml of air.
- The tube is suctioned, and ventilation is commenced. Tube placement in the airway is confirmed with the return of CO_2 and auscultation of the lungs bilaterally.
- The endotracheal tube or tracheostomy appliance is sutured in place. Tracheal ties are applied (Figure 18.13 A,B).

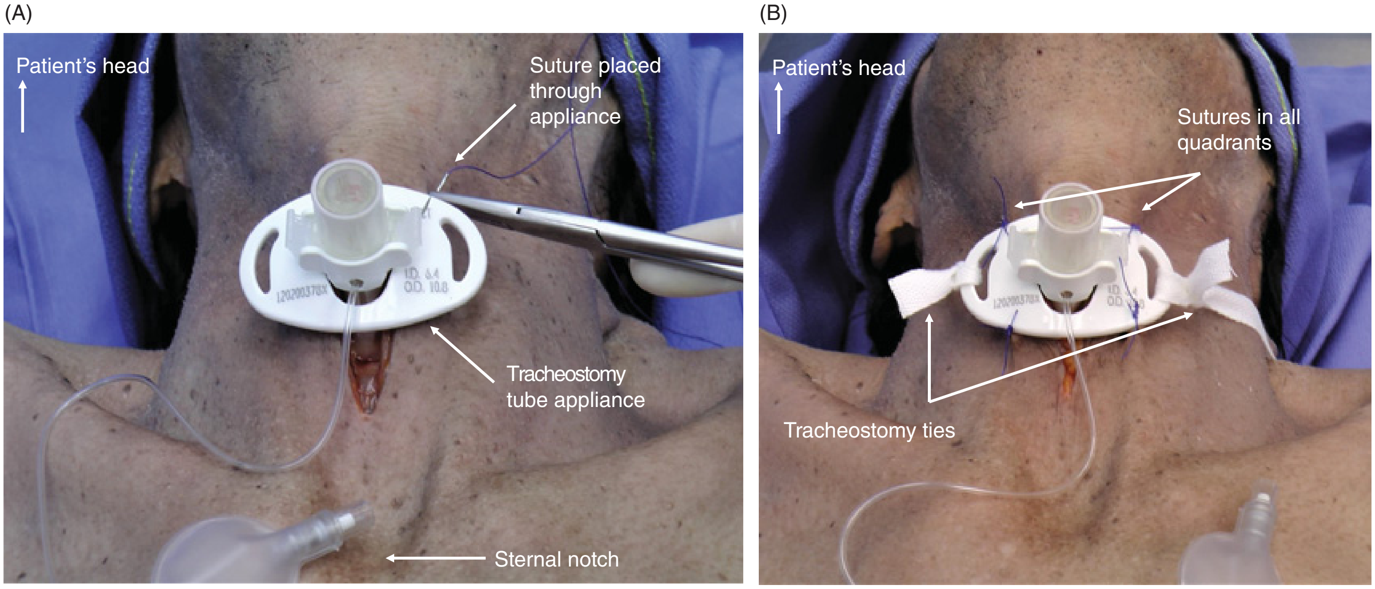

(A)
Patient's head
Suture placed through appliance
Tracheostomy tube appliance
Sternal notch
(B)
Patient's head
Sutures in all quadrants
Tracheostomy ties

Figure 18.13 A,B Securing the tracheostomy tube. The tracheostomy tube is sutured in place through the appliance itself to ensure it is properly secured (A). After suturing the tracheostomy appliance to the skin in four quadrants, tracheal ties are also affixed (B).

Percutaneous Cricothyroidotomy Incision

- The skin incision is landmarked and performed in the same manner as described for open cricothyroidotomy. For percutaneous cricothyroidotomy, a small (1–2 cm) skin incision is made. A vertical incision is preferred in case conversion to open cricothyroidotomy is required. In experienced hands, a transverse incision is an acceptable option.

Procedure

- Connect a syringe half-filled with normal saline to an angiocatheter loaded over a needle. Insert the needle through the cricothyroid membrane via the small skin incision created, angled at 45 degrees and directed toward the carina (Figure 18.14).

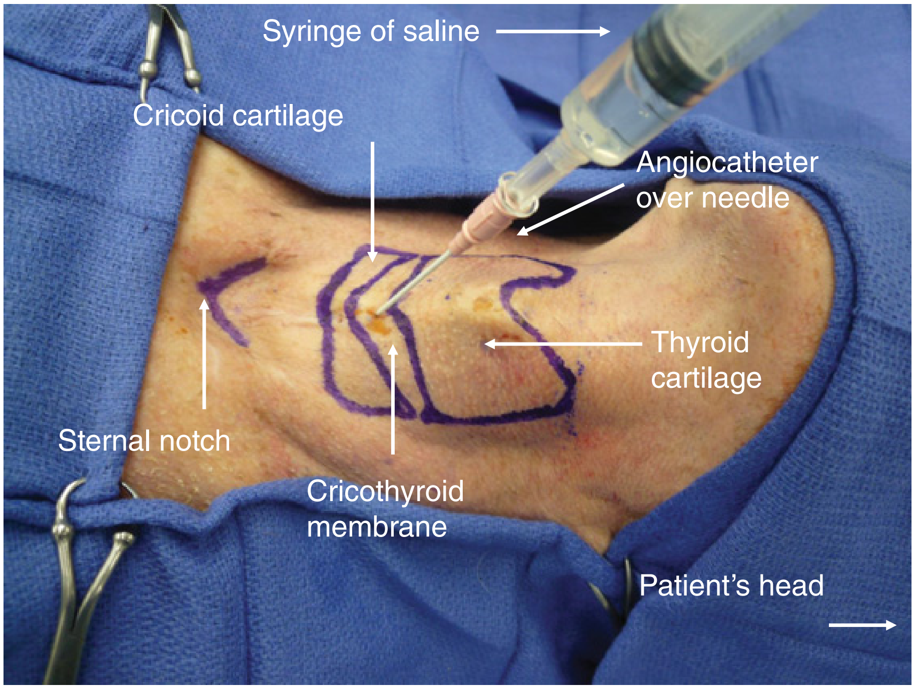

Syringe of saline
Cricoid cartilage
Angiocatheter over needle
Thyroid cartilage
Sternal notch
Cricothyroid membrane
Patient's head

Figure 18.14 Percutaneous cricothyroidotomy: needle insertion. The location of the cricothyroid membrane is externally landmarked in the same manner as for open cricothyroidotomy. A syringe prefilled with a few ml of normal saline is connected to an angiocatheter loaded over a needle. The needle is then inserted into the cricothyroid membrane in the midline, angled at 45 degrees and directed toward the carina. Aspiration of air and a loss of resistance signals entry into the airway.

- Apply negative pressure to the syringe, as it is advanced into the airway through the cricothyroid membrane. Airway entry is heralded by a distinct loss of resistance and aspiration of air bubbles into the syringe.
- Advance the angiocatheter further into the airway while immobilizing the needle and syringe. Hold the angiocatheter secure in the airway and remove the needle and syringe.
- Thread the guidewire into the airway, toward the carina, through the angiocatheter situated in the cricothyroid membrane (Figure 18.15 A,B).
- Remove the angiocatheter over the guidewire.

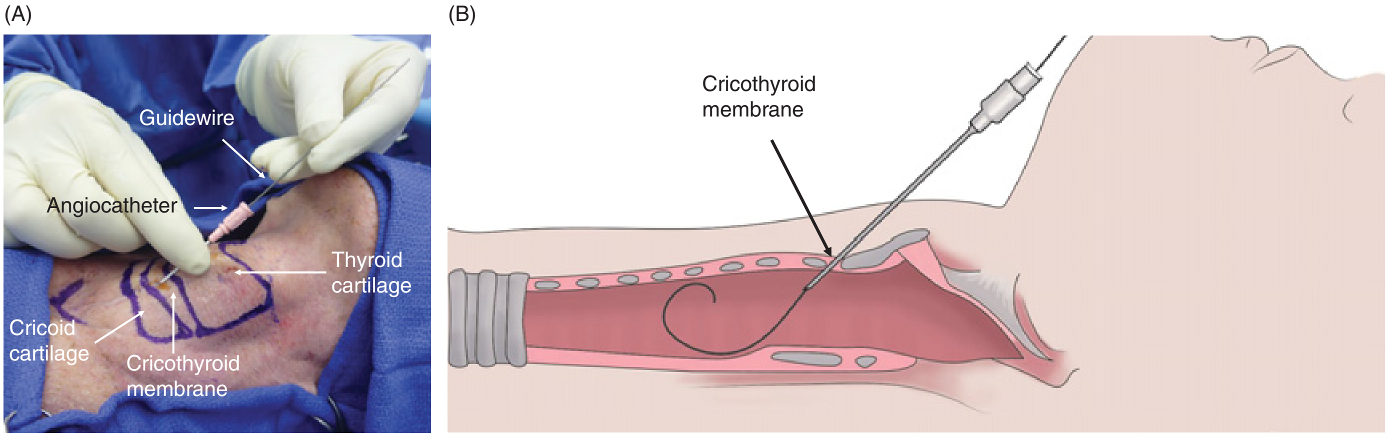

(A)
Guidewire
Angiocatheter
Thyroid cartilage
Cricoid cartilage
Cricothyroid membrane
(B)
Cricothyroid membrane

Figure 18.15 A,B Percutaneous cricothyroidotomy: guidewire insertion. After entry into the airway, the angiocatheter is advanced into the airway, and the syringe and needle are removed. The guidewire is passed through the angiocatheter and into the airway, directed toward the carina (A). Introduction of the guidewire into the airway, through the angiocatheter in the cricothyroid membrane, with an angle toward the carina (B).

- Preload the dilator into the lumen of the cricothyroidotomy tube and insert this over the guidewire into the airway through the cricothyroid membrane, directed toward the carina (Figure 18.16).

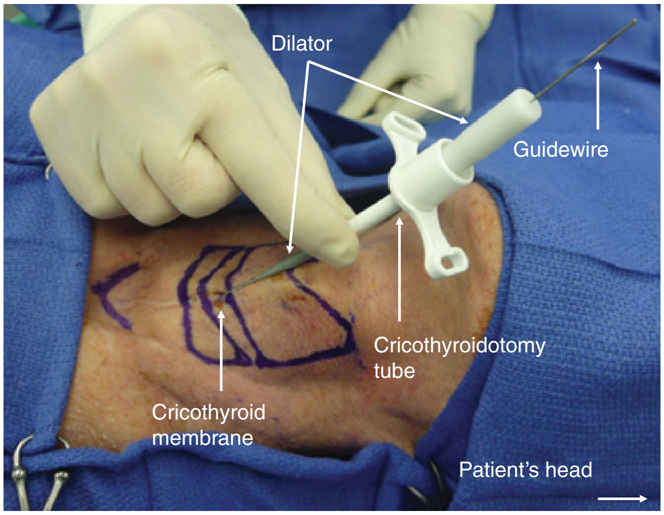


Figure 18.16 Cricothyroidotomy tube insertion. After passing the guidewire, remove the angiocatheter. Preload the dilator into the lumen of the cricothyroidotomy tube, and insert both of these together over the guidewire and into the airway. Directionality toward the carina must be maintained.

- Once the cricothyroidotomy tube is fully inserted, remove the dilator and guidewire together (Figure 18.17).

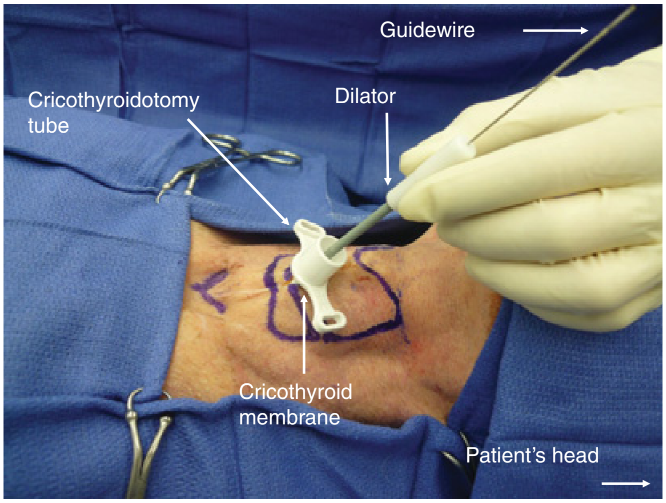


Figure 18.17 Removal of guidewire and dilator. After fully inserting the cricothyroidotomy tube, remove the guidewire and dilator together, leaving the cricothyroidotomy tube in situ. Confirm airway placement, secure the tube, and commence ventilation in the same manner as described for open cricothyroidotomy.

- Commence ventilation and confirm airway placement by return of CO_2 and auscultation of bilateral lung fields. Secure the tube to the skin using both ties and sutures.

Tips and Pitfalls

- Cricothyroidotomy can be challenging in patients with short or thick necks or hematomas due to trauma. In these cases, the cricothyroid space can rapidly be identified with the four-finger technique.
- Never hesitate to enlarge the skin incision. A large skin incision may be a cosmetic nuisance, but a small skin incision can hinder the identification of relevant anatomy or airway tube advancement, both of which can have catastrophic consequences.
- The preferred skin incision for cricothyroidotomy is oriented in a vertical direction. A transverse incision is an acceptable option in experienced hands. The incision in the cricothyroid membrane itself should be transverse.
- Inadvertent pretracheal tube placement can be a disaster. The use of a bougie in the airway and a tracheal hook placed under the thyroid cartilage for elevation can help guide the tube into the airway. Position within the airway should always be confirmed by auscultation and CO_2 return.
- Avoid plunging the scalpel deep into the airway and maintain directionality toward the carina on any instruments inserted into the airway (bougie, angiocatheter, guidewire, dilator, tube). These tips will help avoid posterior airway perforation, which can result in iatrogenic injury to the pharynx or esophagus (Figure 18.18).

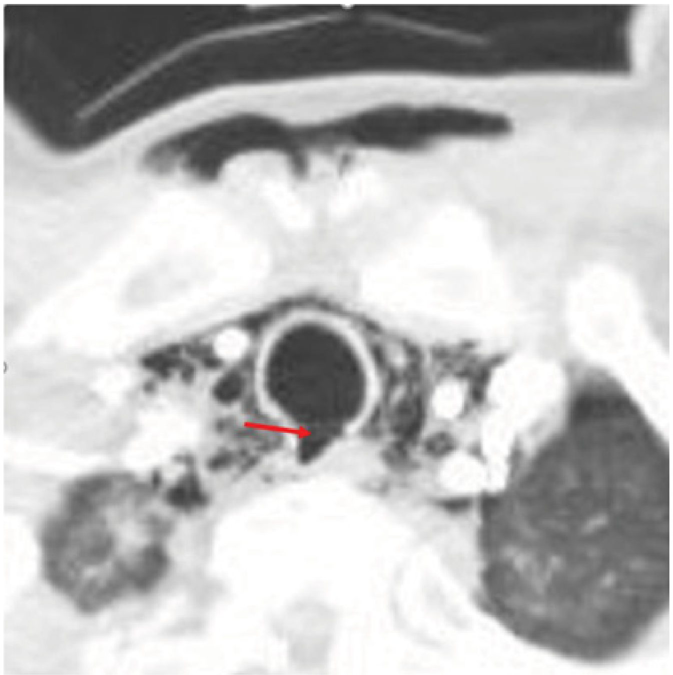


Figure 18.18 Complications of cricothyroidotomy. Iatrogenic injury to the posterior wall of the trachea (arrow) during insertion of the dilator. To avoid this complication, the guidewire, dilator, and bougie should be inserted at an angle, with a direction toward the carina.

Chapter

19

Thoracostomy Tube Insertion

Demetrios Demetriades and Elizabeth R. Benjamin

General Principles

- Tube thoracostomy to treat pneumothorax or hemothorax should be placed in the fourth or fifth intercostal space at the midaxillary line.
- Full personal protective equipment should be used, and the procedure should be performed using standard sterile precautions when possible.
- A single dose of prophylactic antibiotics, such as cefazolin, should be administered – ideally before the procedure. There is no need for further antibiotic prophylaxis.
- Consider autotransfusion in cases with large hemothoraces.
- Traditionally, a tube thoracostomy is placed using the open technique; however, percutaneous techniques, and those using serial dilation, are also acceptable. Care should be taken with trocar techniques due to the high incidence of iatrogenic injuries.

Positioning

The patient should be placed in the supine position with the arm abducted at 90 degrees and elbow fully extended or flexed at 90 degrees cephalad. Adduction and internal rotation of the arm should be avoided, because in this position the latissimus dorsi muscle moves toward the mid-axillary line and might interfere with the tube placement (Figure 19.1 A–C).

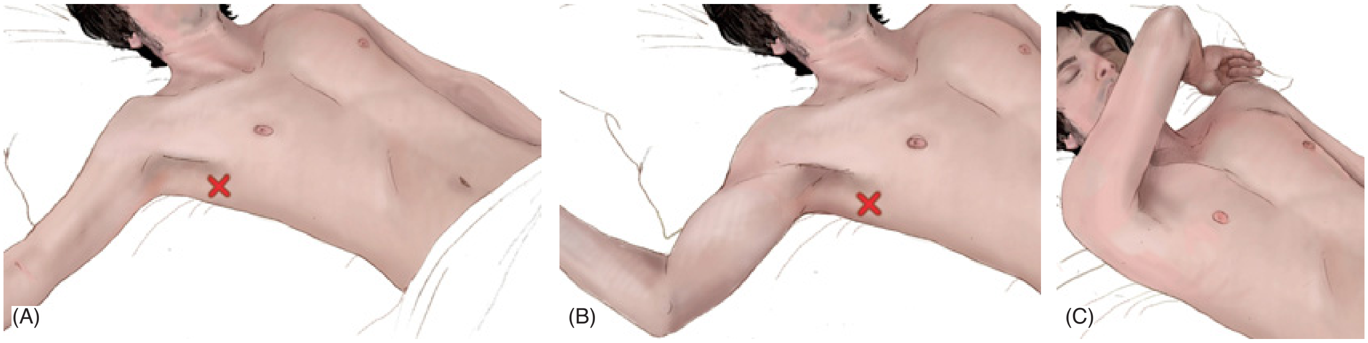


Figure 19.1 A–C The patient should be placed in the supine position with the arm abducted at 90 degrees and elbow fully extended (A) or flexed cephalad at 90 degrees (B). Adduction and internal rotation of the arm is a suboptimal position and should not be used (C). The insertion site should be in the fourth or fifth intercostal space at the midaxillary line, at or slightly above the nipple level.

Site of Tube Insertion

- The tube is inserted in the fourth or fifth intercostal space, mid-axillary line. The external landmark is at or slightly above the level of the nipple in males or in the inframammary crease in females. At this site, the chest wall is thin, containing only skin and intercostal muscles, and is also at a safe distance from the diaphragm, which during expiration can easily reach the sixth intercostal space.

Open Technique

- A 28-F chest tube is usually sufficient in adults. Larger tubes are more difficult and more painful to insert and are no more effective at draining hemothoraces than the smaller tubes. In pediatric patients, tube size is based on the Broselow tape.
- When possible, premedication with systemic analgesia is preferred. Local anesthesia is then injected into the skin, soft tissue, and underlying periosteum.
- A 1.5–2.0 cm transverse incision is made through the skin and subcutaneous fat. Subcutaneous tunneling for the tube placement is not necessary because it makes the procedure painful and does not reduce the risk of empyema or air leak (Figure 19.2).

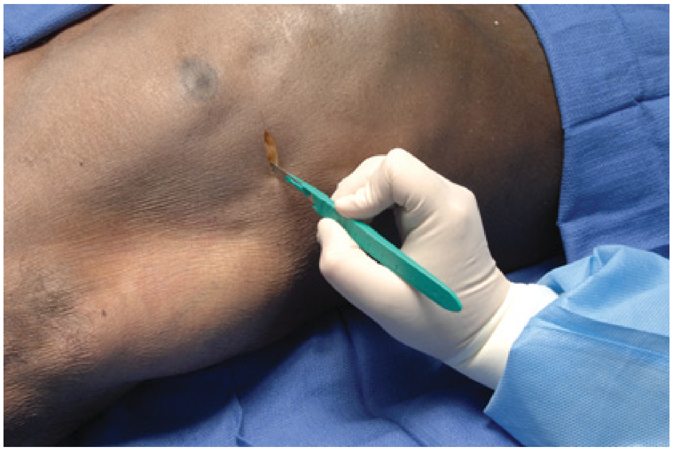


Figure 19.2 1.5–2.0 cm incision is made through the skin and subcutaneous fat, at the fourth or fifth intercostal space midaxillary line.

- A Kelly forceps is used to dissect the intercostal muscles and enter the pleural cavity. The dissection should be kept close to the upper border of the rib to avoid injury to the intercostal vessels, which are located at the inferior border of the rib (Figure 19.3 A,B).

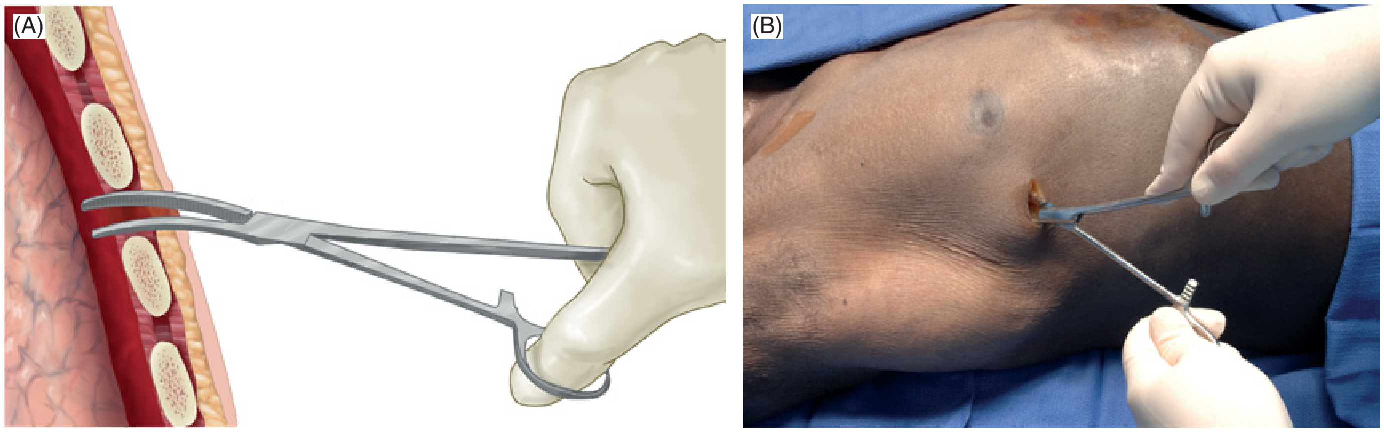
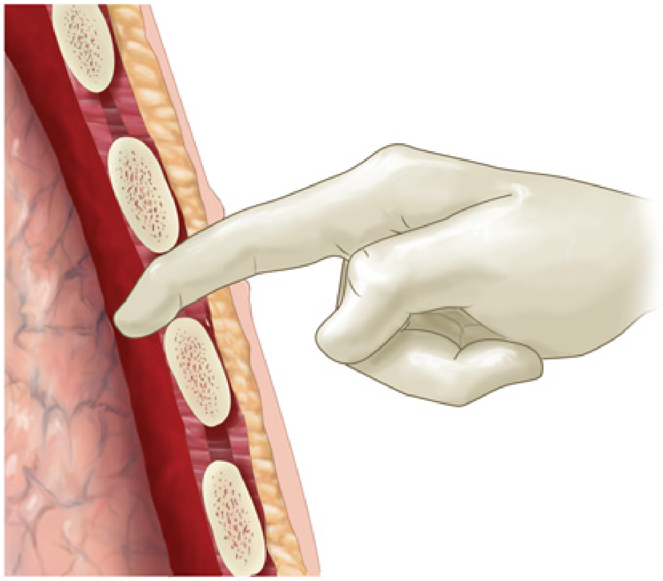


Figure 19.3 A,B Kelly forceps are used to enter the pleural cavity just over the top of the rib. Spreading of the subcutaneous fat and tissue as the Kelly is withdrawn from the pleural cavity.

- If the patient has no previous history of chest trauma or infection, there is no need for routine finger exploration of the pleural cavity. This maneuver is reserved only for cases with suspected pleural adhesions. In these cases, the index finger is inserted in the pleural cavity and swept 360 degrees, to evaluate for adhesions and avoid intraparenchymal placement of the tube (Figures 19.4).



Figures 19.4 Digital exploration of the pleural cavity to rule out adhesions.

- The tube is then inserted into the thoracic cavity, exerting gentle pressure. A clamp may be placed at the fenestrated end of the tube to help guide the tube into the chest. During insertion, a clamp should be placed on the distal end of the tube to protect the operator from blood spillage. The tube is advanced in a posterior and superior direction to guide the tip toward the apex of the pleural cavity. A gentle turn may be introduced while advancing the tube, but avoid a corkscrew motion, as this can result in iatrogenic damage to the lung parenchyma. If resistance is encountered, draw back the tube. In a normal weight adult, the tube should be inserted 8–10 cm (Figure 19.5, Figure 19.6).

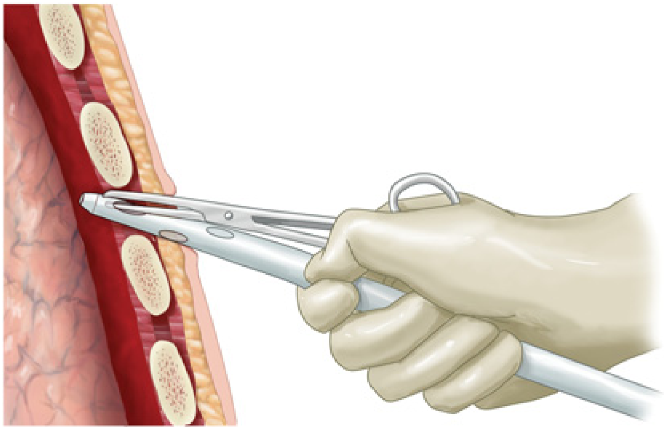


Figure 19.5 The tube is grasped with a Kelly clamp at the distal fenestration and is firmly forced into the pleural cavity.

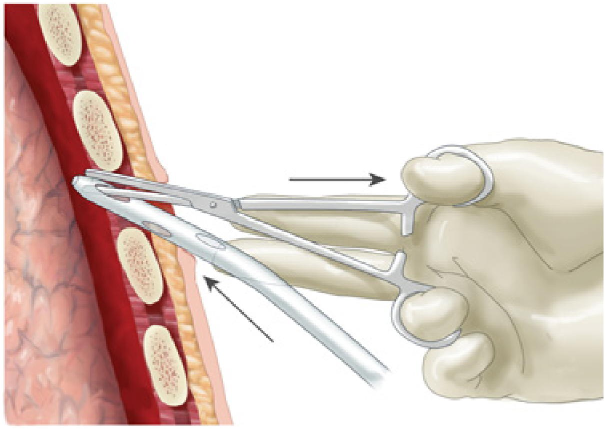


Figure 19.6 When the tip of the tube enters the cavity, the clamp is released and withdrawn, while the tube is advanced toward the apex and posteriorly.

- The end of the tube is connected to a collection system at –20 cm H_2O. In most systems, the suction level is adjusted on the collection system and does not require titration of the wall suction unit.
- The chest tube is then sutured in place. If the skin incision is large relative to the tube size, the excess incision can be reapproximated using interrupted sutures or staples (Figure 19.7 A–C).

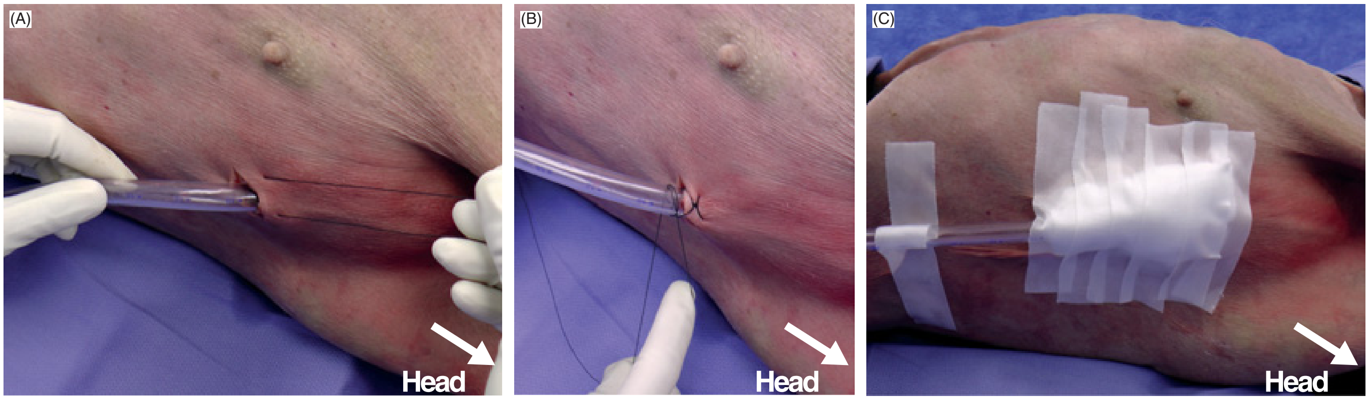


Figure 19.7 A–C The tube is secured in place with 0 silk suture. A horizontal mattress suture may be placed around the tube and left untied to be used for wound closure at the time of tube removal. The tube is further secured to the thoracic wall with adhesive tape.

- An occlusive dressing is placed around the entry site, and the tube is further secured to the thoracic wall with adhesive tape.
- If the clinical condition allows, the patient is encouraged to sit up, take deep breaths, and cough to facilitate lung re-expansion and blood drainage.

Percutaneous Technique

- The percutaneous dilational technique is another less-invasive option for inserting a thoracostomy tube. The system is commercially available in packages that contain all needed supplies (Figure 19.8).

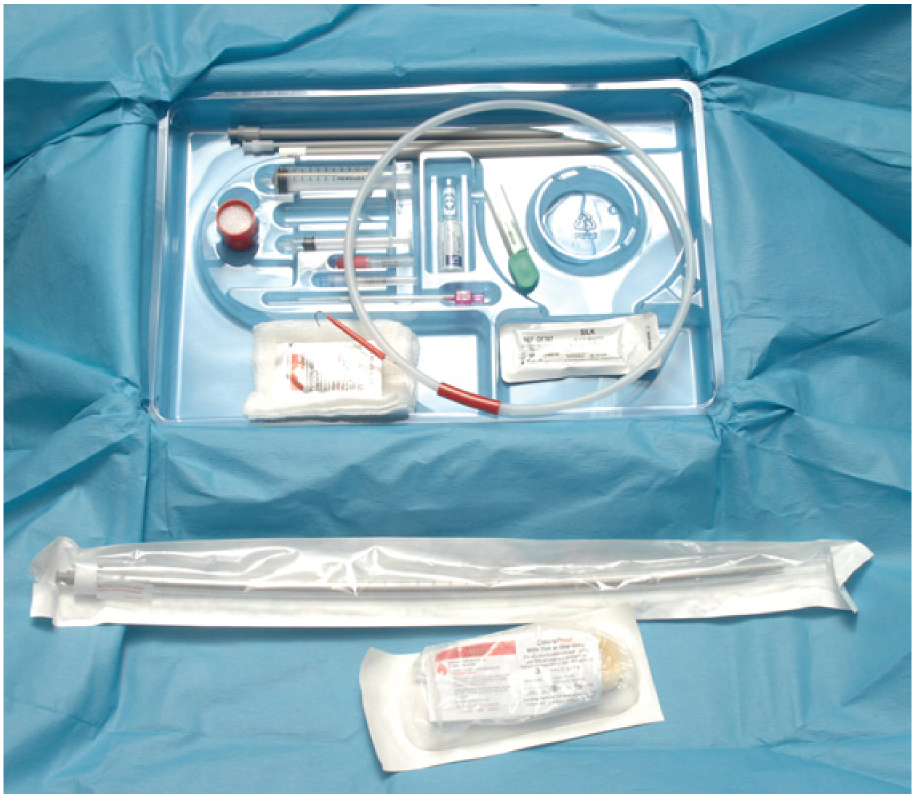


Figure 19.8 Percutaneous chest tube tray.

- Similar to the open technique, systemic and local analgesia is administered prior to the procedure.
- An introducer needle, attached to a syringe with sterile saline, is inserted into the pleural cavity at the upper border of the rib to avoid injury to the intercostal vessels. Entry into the pleural cavity is confirmed by aspiration of air or blood.
- Using the Seldinger technique, a guidewire is inserted through the needle and the needle is removed. A skin incision slightly longer than the diameter of the chest tube is made at the needle insertion site.
- The dilator is inserted over the guidewire in a push/twist fashion, aiming slightly posteriorly and toward the apex of the pleural cavity (Figure 19.9, Figure 19.10, Figure 19.11, Figure 19.12).

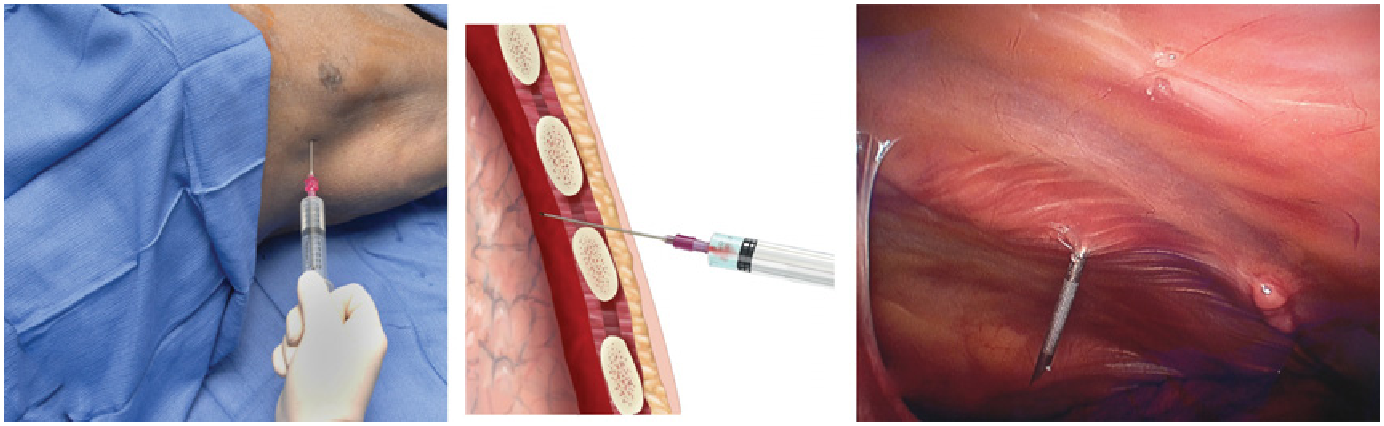


Figure 19.9 The introducer needle with a syringe with saline is used to confirm entrance into the thorax with the return of blood or air bubbles. It is inserted in the fourth or fifth intercostal space, just above the rib, to avoid injury to the neurovascular bundle.

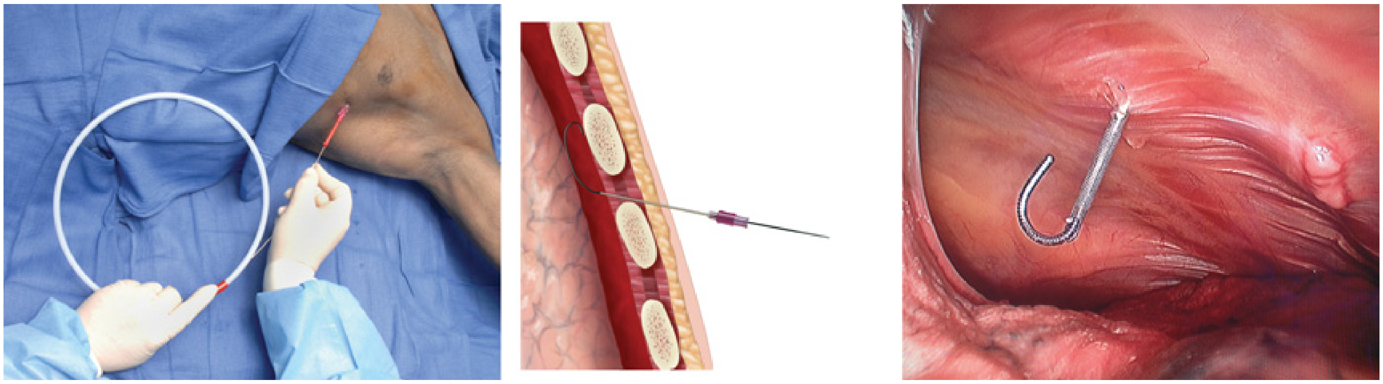


Figure 19.10 A guidewire is inserted through the introducer needle, and the needle is removed.

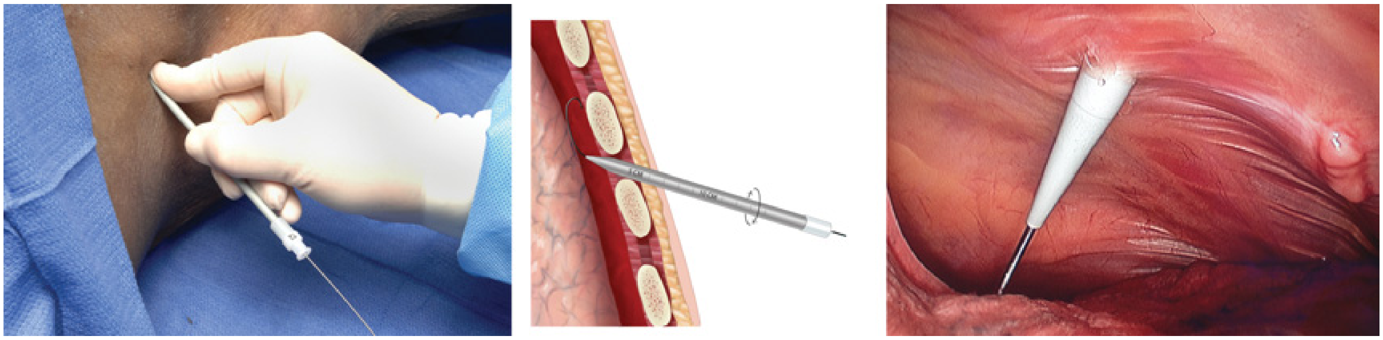


Figure 19.11 Using the Seldinger technique, the tract is sequentially dilated after making a small skin incision.

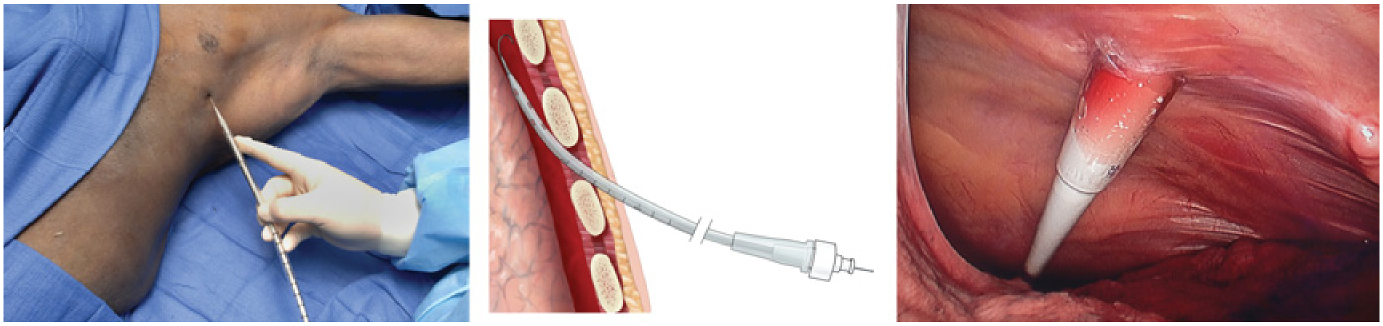


Figure 19.12 The tube is passed into the thoracic cavity over the guidewire. The guidewire is removed, and the tube is secured to the skin.

- The dilator is then removed, and the chest tube is inserted over the guidewire, advancing 8–10 cm into the pleural cavity in a normal-sized adult. No resistance should be encountered when advancing the chest tube.
- The guidewire is removed and the tube is connected to the collection system, and secured to the skin, as described previously.

Autotransfusion

- Blood autotransfusion should be considered in patients with large hemothoraces. There are numerous commercially available autotransfusion systems, which are easy and fast to assemble and use.
- Sodium citrate is added to the collected blood, at a ratio of 1 ml per 10 ml of blood (Figure 19.13 A,B).

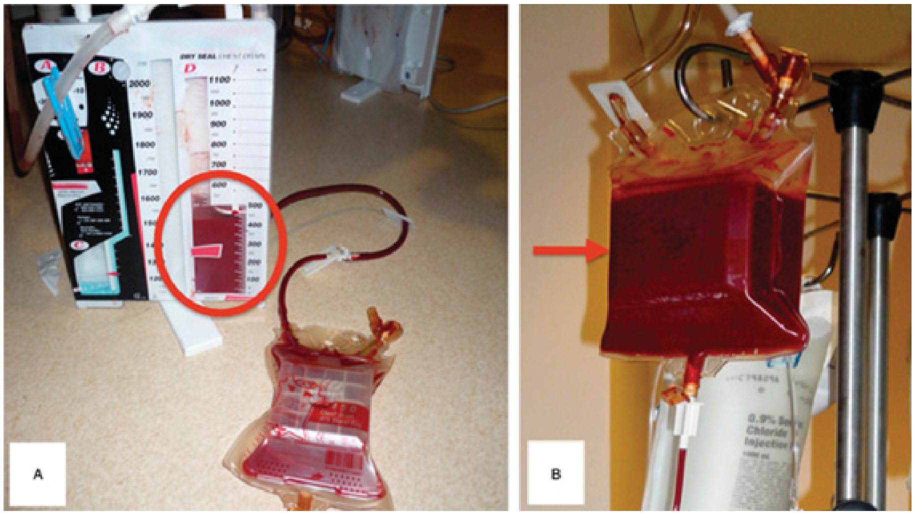


Figure 19.13 A,B Autotransfusion system. There are numerous commercially available autotransfusion systems, which are easy and fast to assemble and use.

Removal of the Chest Tube

- The chest tube should be removed as soon as possible. Indicators that the chest tube is ready for removal include lack of air leak, output less than about 100 ml/24 hrs, and imaging confirming resolution of hemo- or pneumothorax. Delayed tube removal increases the risk of empyema formation.
- The tube can be removed in deep inspiration or expiration. An upright chest X-ray should be obtained to ensure good expansion of the lung and no significant residual pneumothorax.

Technical Complications

- Technical complications are common during insertion of chest tubes, especially if performed by inexperienced physicians. They include extrapleural placement, kinking of the tube resulting in inadequate drainage, iatrogenic injury to the lung, diaphragm, liver, spleen, and the heart (Figure 19.14, Figures 19.15 A,B, Figure 19.16 A,B, Figure 19.17 A,B, Figure 19.18).

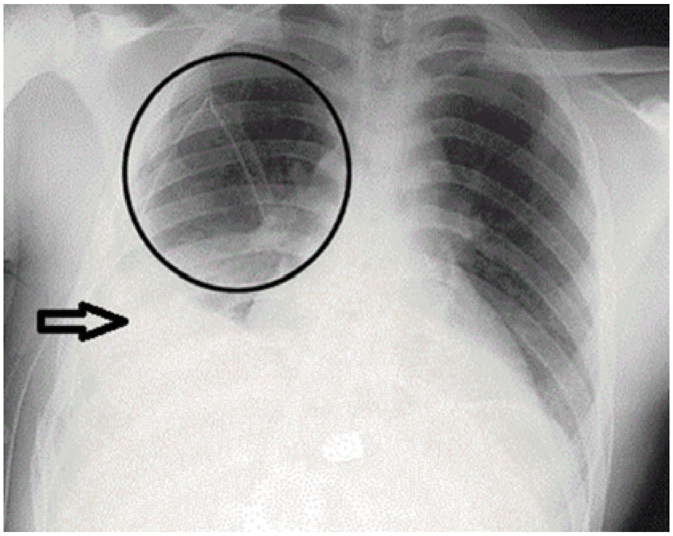
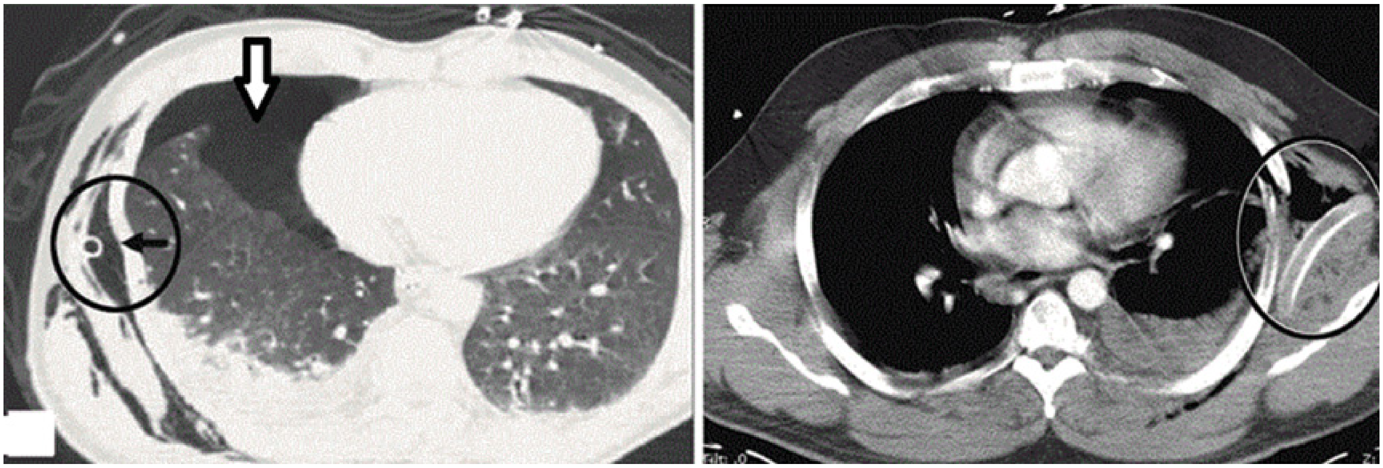


Figure 19.14 A malpositioned right thoracostomy tube that kinks (circle), becoming ineffective in draining. Note the large residual hemothorax (arrow).



Figures 19.15 A,B Patient with malpositioned right thoracostomy tube in the subcutaneous tissue (circle) and a large undrained pneumothorax (arrow; A). Patient with left misplaced tube in the subcutaneous tissues (circle; B).

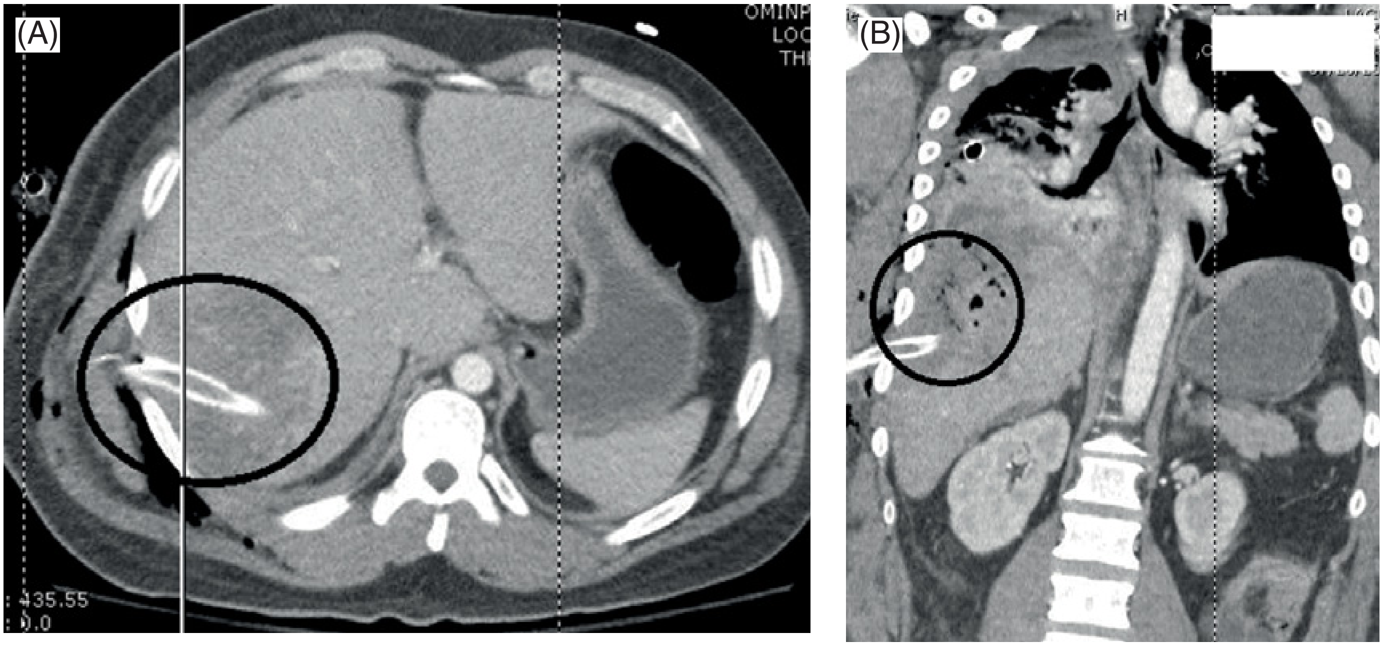


Figure 19.16 A,B Patient with a malpositioned right thoracostomy tube that was inadvertently placed into the liver, resulting in a liver hematoma (circle).

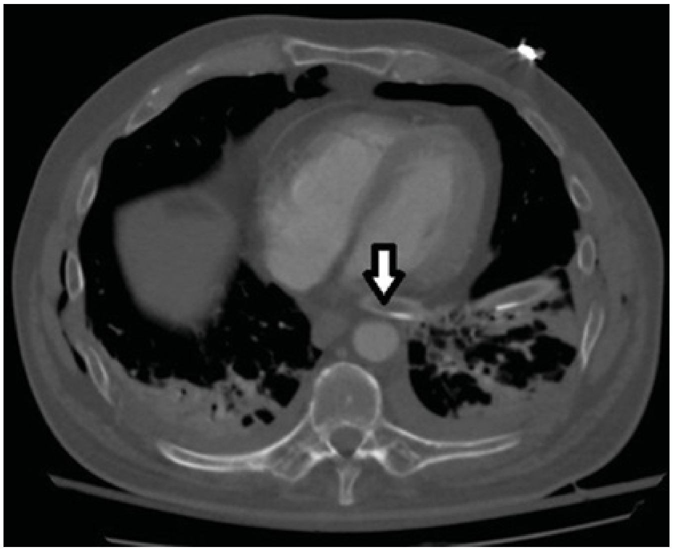


Figure 19.17 A,B A malpositioned left thoracostomy tube, with the tip in the mediastinum, anterior to the aorta (arrow).

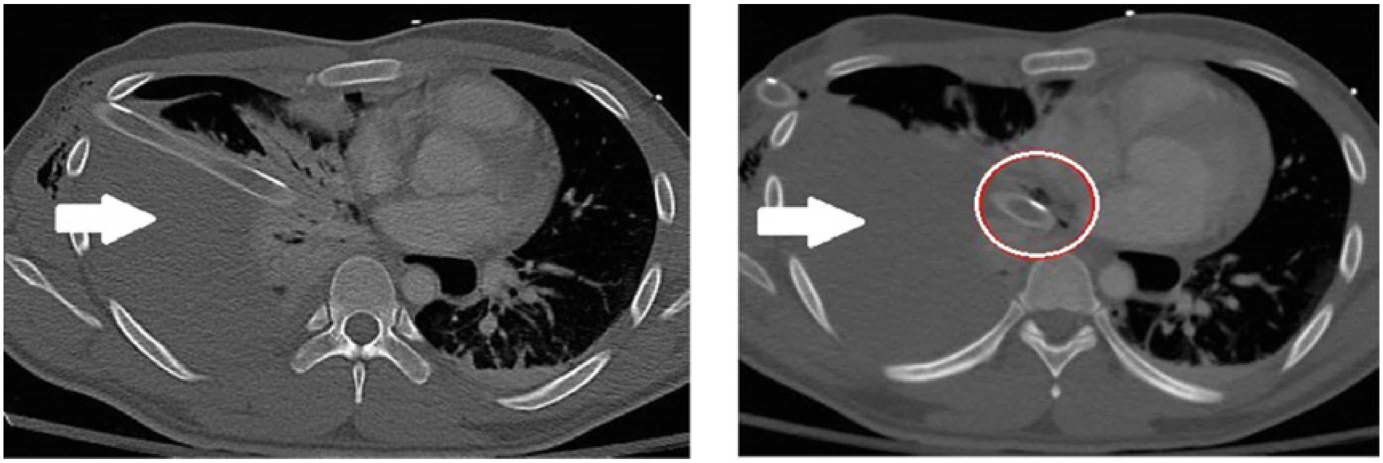


Figure 19.18 Patient with a right thoracostomy tube misplaced in the heart (circle) resulting in severe bleeding and a large hemothorax (arrows). The patient needed an emergency thoracotomy and cardiac repair.

Tips and Pitfalls

- Misplacement of the tube into the subcutaneous tissues may occur, especially in obese patients.
- Iatrogenic injuries to the diaphragm, liver, or spleen may occur if the insertion site is too low (below the level of the nipple in males and the inframammary crease in females).
- The trocar style chest tubes should be reserved only for those providers with extensive experience. Iatrogenic injuries to the heart and lung may occur.
- Insertion of the tube into the lung parenchyma may occur in patients with pleural adhesions due to previous chest trauma, previous thoracotomy, or infections. In these cases, digital exploration of the pleura for adhesions should be performed before the insertion of the tube.
- Kinking of the tube resulting in poor drainage and may occur if the tube is inserted too far into the pleural cavity. In a normal habitus adult patient, do not insert the tube beyond 8–10 cm.
- Persistent air leak after tube placement is most commonly due to technical problems and all sites of potential leakage should be examined. Air can leak from a side hole of the tube located outside of the chest cavity, a large skin incision that is not sealed, or a problem with the tube connections of the collection system. If there is no technical problem, the differential diagnosis should include a significant lung laceration or injury to tracheobronchial tree.
- Large size tubes (>32-F) are not more effective in draining a hemothorax. They are more difficult to insert and more uncomfortable for the patient. For a pneumothorax, a small 16- or 18-F tube is sufficient.
- After insertion of the tube, if clinical condition permits, encourage the patient to cough while sitting up and in supine and lateral positions to promote lung expansion and drainage of any hemothorax before it clots.
- Suspected significant residual hemothorax on chest X-ray should be evaluated by a CT scan as soon as possible. The plain film is not reliable in distinguishing among lung contusion, atelectasis, and residual hemothorax!

Chapter

20

Emergency Room Resuscitative Thoracotomy

Demetrios Demetriades and Elizabeth R. Benjamin

General Principles

- In traumatic cardiac arrest, especially due to hemorrhage or cardiac tamponade, external cardiac compression has no role in the emergency room.
- Trauma patients that arrive at the emergency room in, or progress, to cardiac arrest are candidates for resuscitative thoracotomy. The indications and contraindications are controversial, with many surgeons supporting strict criteria and others supporting liberal criteria for the procedure.
- The emergency room thoracotomy can be resuscitative and/or therapeutic, allowing release of cardiac tamponade, control of bleeding, direct cardiac massage, and defibrillation, aortic cross-clamping, and management of air embolism.
- Endotracheal intubation, intravenous line placement, and thoracotomy can be performed simultaneously.

Special Surgical Instruments

- All staff should wear personal protective equipment.
- The resuscitative thoracotomy tray should be immediately available in the emergency room. It includes only essential instruments (one scalpel, Finochietto retractor, two Duval lung forceps, two vascular clamps, one long Russian forceps, four hemostats, one bone cutter, one pair of long scissors). In addition, good lighting, suction, and an internal defibrillator should be ready before patient arrival (Figure 20.1).
- An epicardial pacing device and wires should be immediately available.

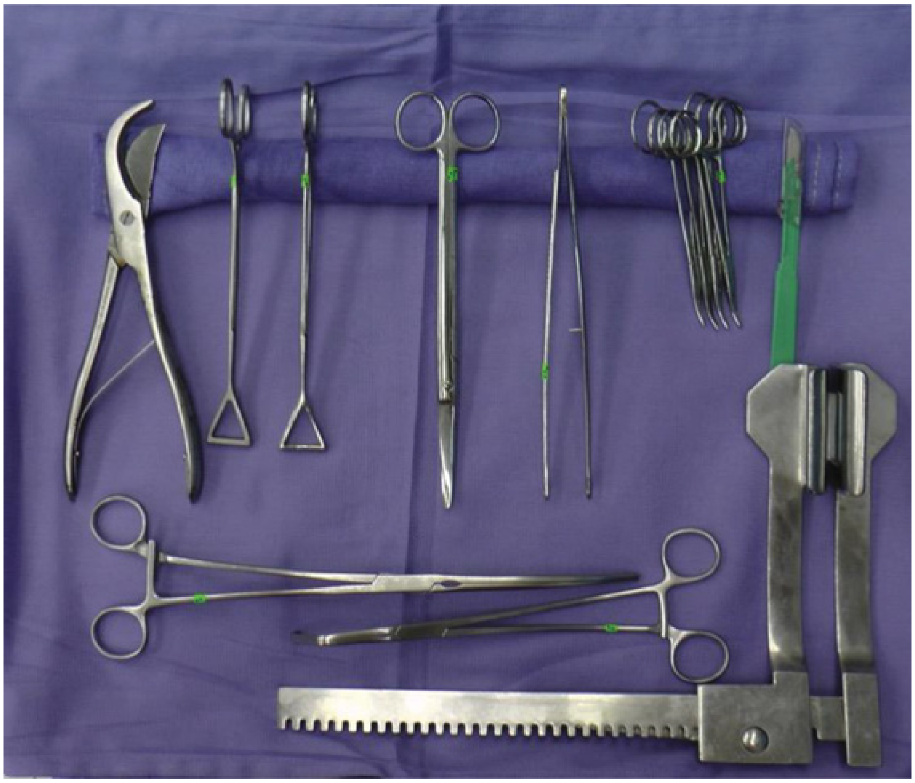


Figure 20.1 The emergency room thoracotomy tray includes only the absolutely essential instruments (scalpel, Finochietto retractor, two Duval lung forceps, two vascular clamps, one long Russian forceps, four hemostats, one bone cutter, long scissors).

Positioning

- Supine position with the left arm abducted at 90 degrees or above the head. Antiseptic skin preparation is performed with betadine on the anterior and left lateral chest wall.

Incision

- A left anterolateral incision allows exposure to the heart and left lung, as well as access to the thoracic aorta for placement of a cross-clamp. If necessary, it can be extended as a clamshell incision into the right chest through a mirror incision and division of the sternum.
- The incision is performed through the fourth and fifth intercostal space, just below the nipple in males or the inframammary crease in females. The incision starts at the left parasternal border and curves toward the axilla, ending at the posterior axillary line.
- The intercostal muscles are divided close to the superior border of the rib, in order to avoid damage to the neurovascular bundle, and the pleural cavity is entered using scissors. Right mainstem intubation or holding ventilation during entry into the pleural cavity reduces the risk of lung injury (Figure 20.2 A–C).
- A Finochietto retractor is inserted and the ribs are spread. The bar of the Finochietto is placed on the axilla side to allow unobstructed access to the sternum, should a right-sided extension be required. The left lower lobe of the lung is grasped with Duval forceps and retracted laterally and cephalad to expose the heart and the thoracic aorta (Figure 20.3).

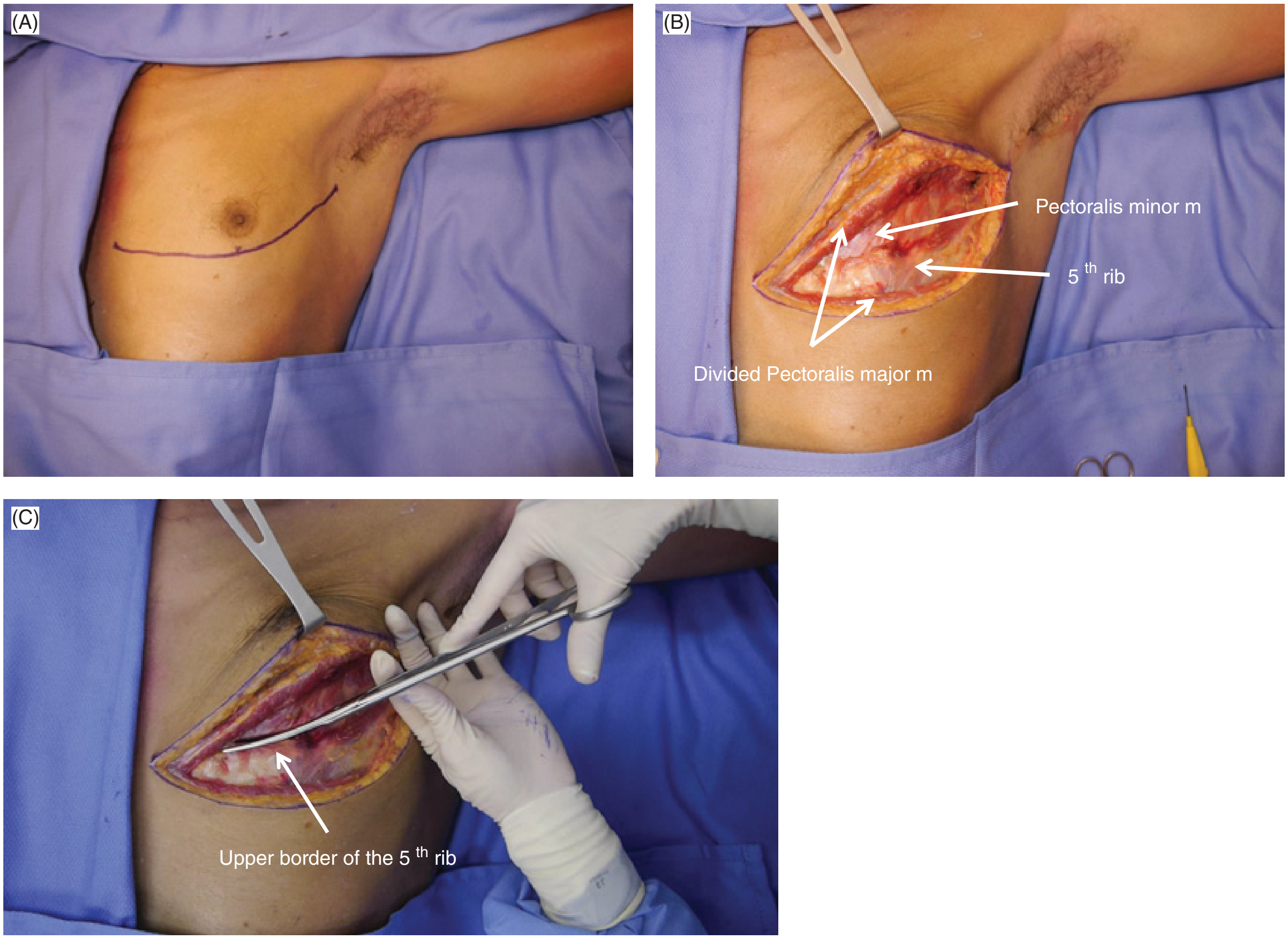


Figure 20.2 A–C The resuscitative thoracotomy incision is placed just below the nipple in males or in the inframammary crease in females (through the fourth and fifth intercostal space). It starts at the left parasternal border and extends to the mid-axillary line, with a direction toward the axilla. The intercostal muscles are divided at the superior border of the rib with scissors, taking care to avoid injury to the lung.

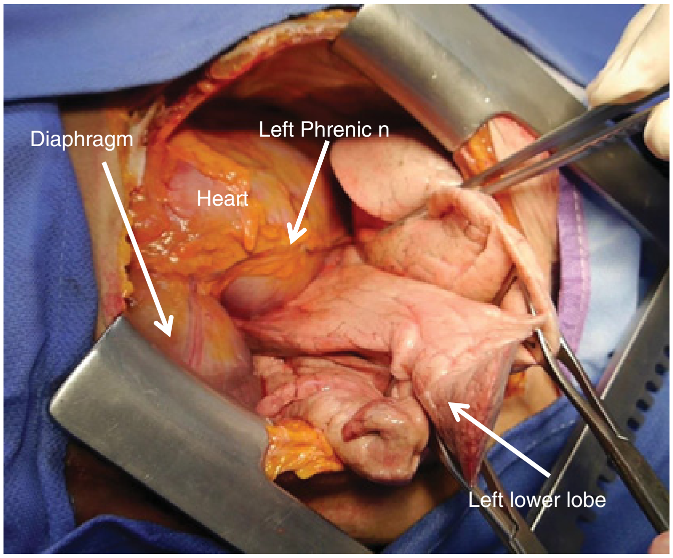


Figure 20.3 The left lower lobe of the lung is grasped with Duval forceps and retracted toward the patient's head and laterally to improve the exposure of the heart and the thoracic aorta.

- In suspected right chest or mediastinal vascular injuries, extend the left thoracotomy into a clamshell incision, by transverse division of the sternum with a bone cutter and a symmetrical right thoracotomy. During the division of the sternum, both internal mammary arteries are transected, and clamping or ligation should be performed after the restoration of cardiac activity and circulation (Figure 20.4 A,B).

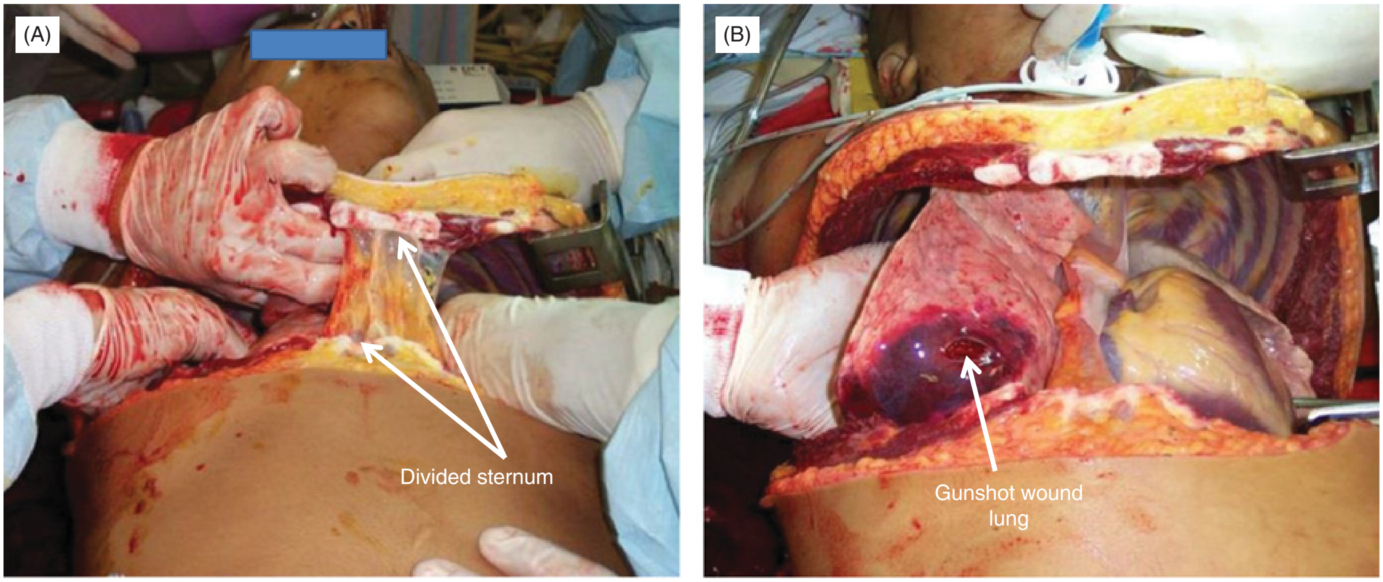


Figure 20.4 A,B Clamshell incision: The left thoracotomy incision is extended through a transverse division of the sternum into a symmetrical right thoracotomy. It provides good exposure of the anterior aspect of the heart, the superior mediastinal vessels, and both lungs.

Procedure

- Upon entering the left pleural cavity, any hemothorax is evacuated and significant bleeding from the lung or thoracic vessels is controlled by direct pressure or placement of a vascular clamp.
- The pericardium is then opened in a cephalo-caudal direction, anterior to the phrenic nerve. Entry into the cardiac sac should be done sharply in the setting of tamponade, as grasping the tense pericardium with forceps will be futile.
- A generous incision should be used to open the pericardium. Incomplete opening of the pericardium may impede venous return or cause strangulation of the heart once resuscitation is complete (Figure 20.5 A–C).

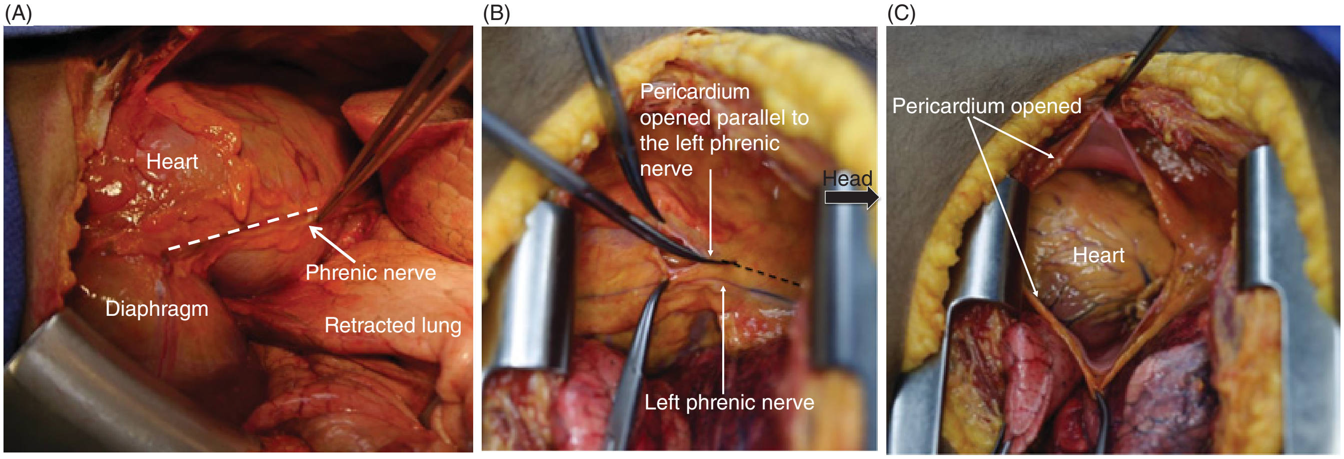

(A)
Heart
Phrenic nerve
Diaphragm
Retracted lung
(B)
Pericardium opened parallel to the left phrenic nerve
Head
Left phrenic nerve
(C)
Pericardium opened
Heart

Figure 20.5 A–C The phrenic nerve is seen on the lateral border of the pericardium and should be protected. The pericardium is opened anterior and parallel to the nerve (A). The pericardium is open anterior and parallel to the phrenic nerve (B). After opening the pericardium, the heart can easily be evaluated (C).

- Tamponade is released and cardiac bleeding controlled by finger compression. Injuries may then be repaired with non-absorbable 2–0 or 3–0 suture on a large tapered needle using a figure of eight or U-stitch based on injury location. Use caution if inflating a Foley catheter into a cardiac wound for hemostasis, as this may cause additional damage to the tissue or expand the wound. Skin staples may be used to temporarily control bleeding from cardiac stab wounds in extreme cases; however, these are ineffective in gunshot wound injuries and are associated with cardiac tissue loss and tearing of the injury. Care should be used to minimize staple use, as all staples will ultimately need to be removed and the injury sutured (Figure 20.6, Figure 20.7).

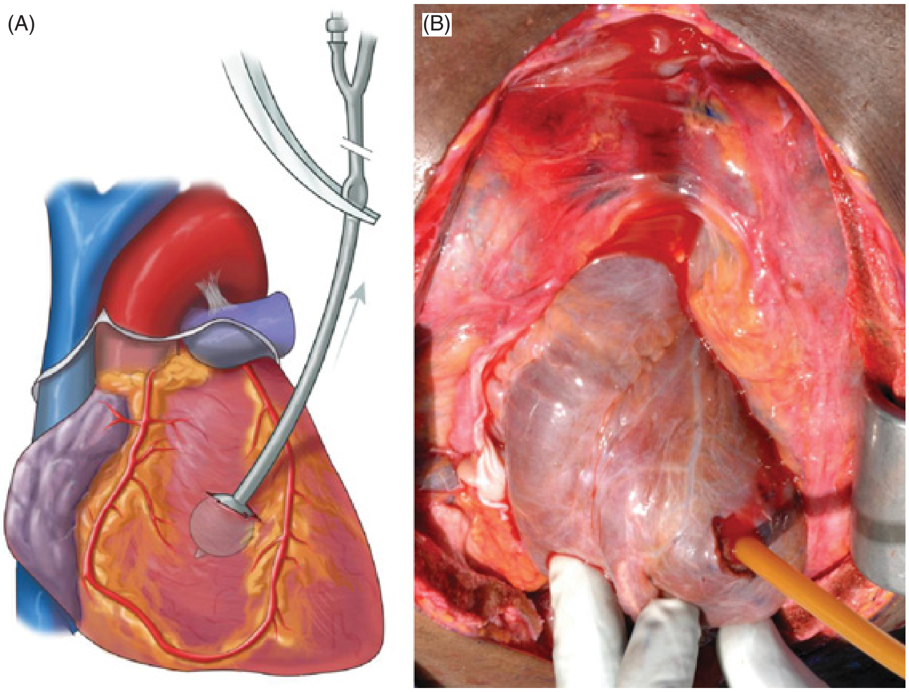


Figure 20.6 A,B In some cases, with small cardiac wounds, temporary bleeding control may be achieved by inserting and inflating a Foley catheter. Avoid excess traction on the Foley catheter, as this can enlarge the laceration.

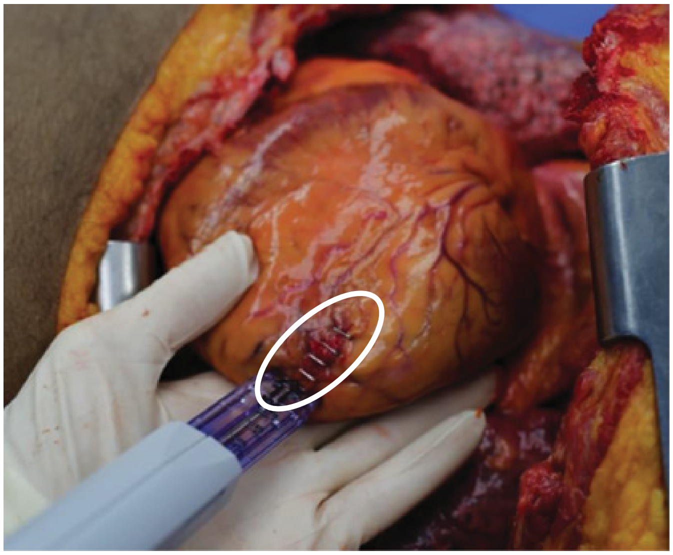


Figure 20.7 A skin stapler can be used for temporary closure of cardiac stab wounds. The cardiac wound is definitively repaired with figure of eight, or horizontal mattress, using nonabsorbable 2-0 or 3-0 suture.

- Cardiac massage should always be performed using both hands.
- Internal cardiac defibrillation is performed in cases with ventricular fibrillation or pulseless ventricular tachycardia. The two internal cardiac paddles are placed on the anterior and posterior wall of the heart and a shock is delivered with 10–50 joules (Figure 20.8).
- Resuscitation should be ongoing during the resuscitative thoracotomy, including administration of calcium, epinephrine, and sodium bicarbonate as appropriate.
- The aortic cross-clamp is most easily placed on the thoracic aorta approximately 4 cm above the level of the diaphragm. Exposure of the aorta is facilitated by retracting the left lower lobe of the lung cephalad with a Duval clamp. The inferior pulmonary ligament may be divided along the avascular plane to improve exposure. Be cognoscente of the inferior pulmonary vein, marking the endpoint of this dissection.

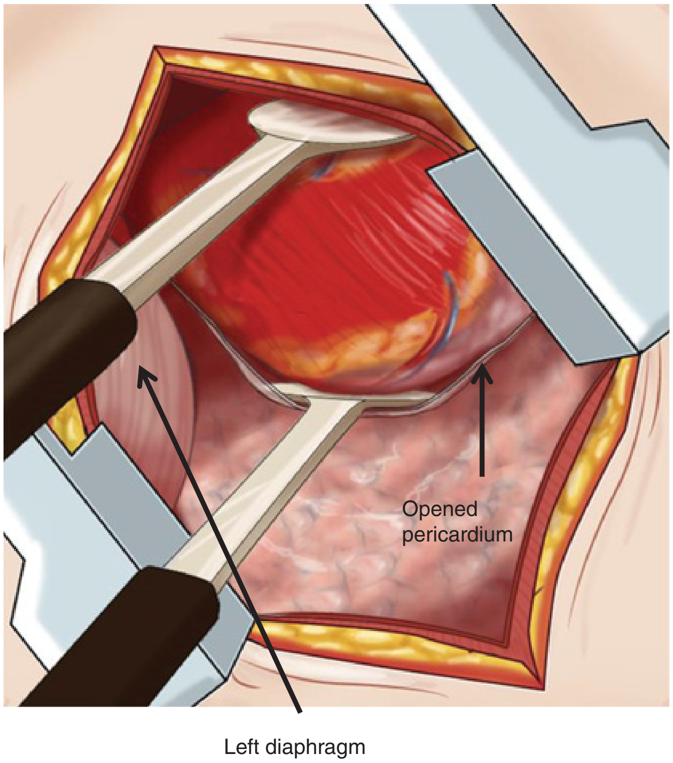


Figure 20.8 Internal defibrillation. The two internal cardiac paddles are placed on the anterior and posterior wall of the heart.

- In cardiac arrest, the aorta is collapsed and not pulsating and may not be easy to identify. The aorta is the first structure felt while sliding the fingers along the left posterior thoracic wall toward the spine. The mediastinal pleura over the aorta is then incised using long scissors and a vascular clamp is applied. Care must be taken to avoid incorporating or damaging the esophagus that lies directly anterior and medial to the aorta. Cranial and caudal dissection of the aorta are minimized due to risk of avulsion of the intercostal arteries. The aortic clamp is removed as soon as the cardiac activity returns and the carotid pulse is palpable (Figure 20.9 A,B).

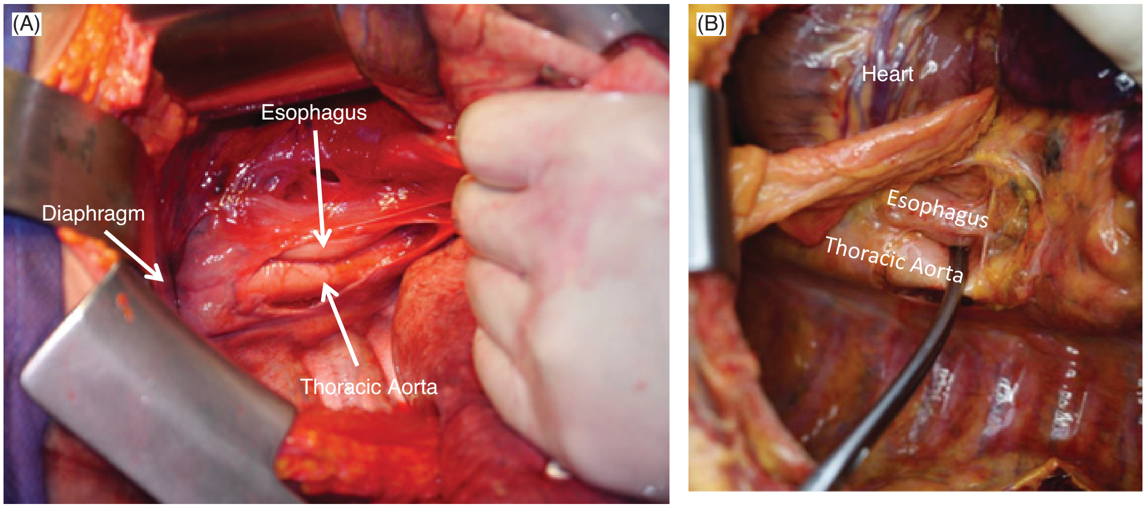

(A)
Esophagus
Diaphragm
Thoracic Aorta
(B)
Heart
Esophagus
Thoracic Aorta

Figure 20.9 A,B Cross-clamping of the thoracic aorta: The mediastinal pleura over the aorta is incised. Note the esophagus anteriorly and medially. The esophagus may be mistaken for the aorta if there is no pulse and the aorta is collapsed (A). Vascular clamp applied on the thoracic aorta (B).

- Epicardial pacing should be considered in patients with arrhythmias. The pacing wires are placed on the upper part of the anterior wall of the right ventricle – one at the top of the ventricle and the second approximately 1 cm below. The epicardial wires have a small needle on one end. This needle is used to embed the wires superficially in the myocardium, after which the needle is cut off. A larger needle on the other end of the wire is used to pierce the chest wall and bring the wire to the skin surface. The exteriorized wires are then connected to the pacer. The usual settings for the pacer are a heart rate of 70–90 per minute and a maximal current output of 10 mA (Figure 20.10 A,B).

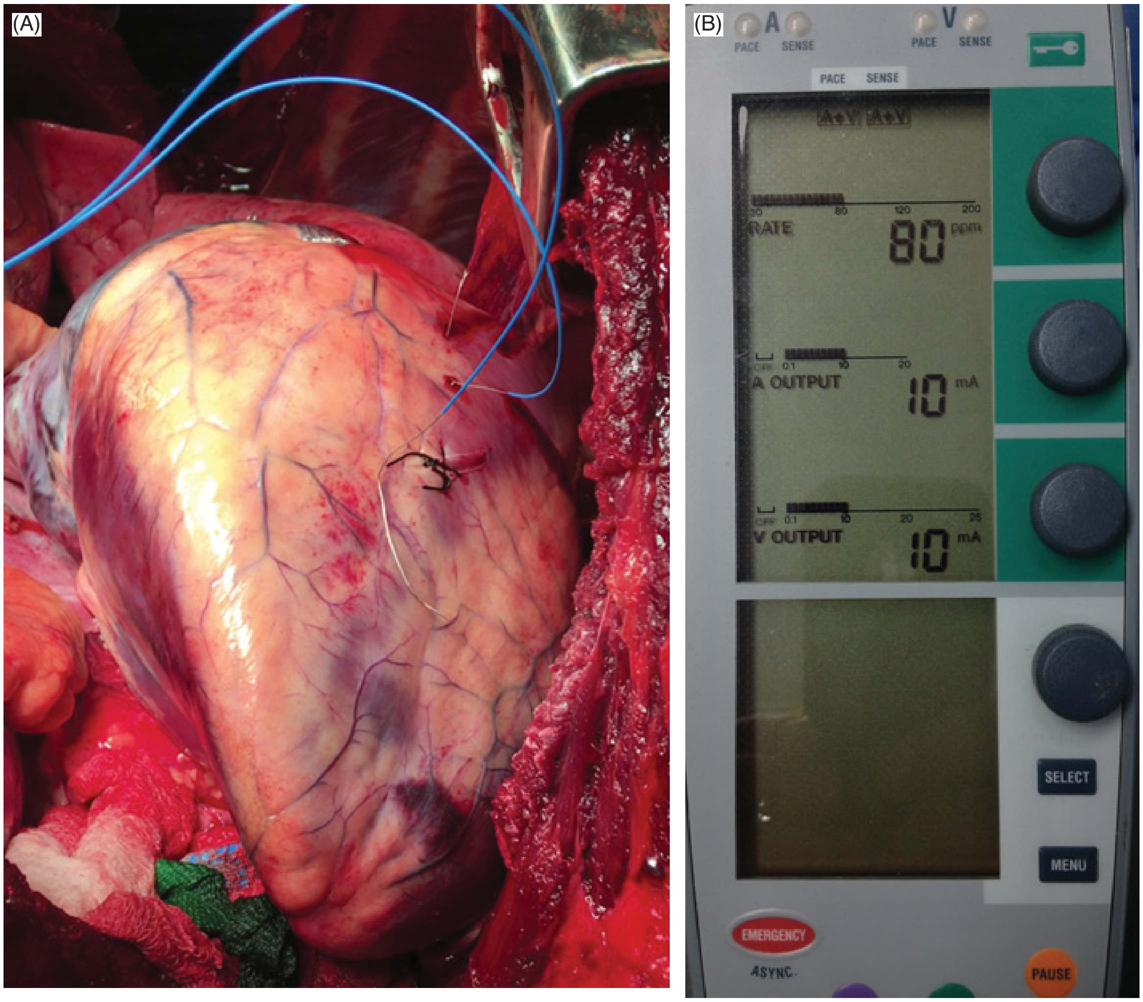

(A)
(B)
A
PACE
SENSE
V
PACE
SENSE
PACE
SENSE
A+V
A+V
30
80
120
200
RATE
80 ppm
OFF
0.1
10
20
A OUTPUT
10 mA
OFF
0.1
10
20
25
V OUTPUT
10 mA
SELECT
MENU
EMERGENCY
ASYNC.
PAUSE

Figure 20.10 A,B The pacing wires are placed in the epicardium, on the upper part of the anterior wall of the right ventricle, about 1 cm apart (arrows; A). External cardiac pacer: The usual settings of the pacer are heart rate 70–90 per minute and V output 10 mA (B).

- In patients with injuries to the low-pressure cardiac chambers, the lung, or major veins, air embolism may develop. In extreme cases, air bubbles can be seen in the coronary veins. In the event of air embolism, the source should be rapidly controlled and the air aspirated from the ventricles (Figure 20.11).

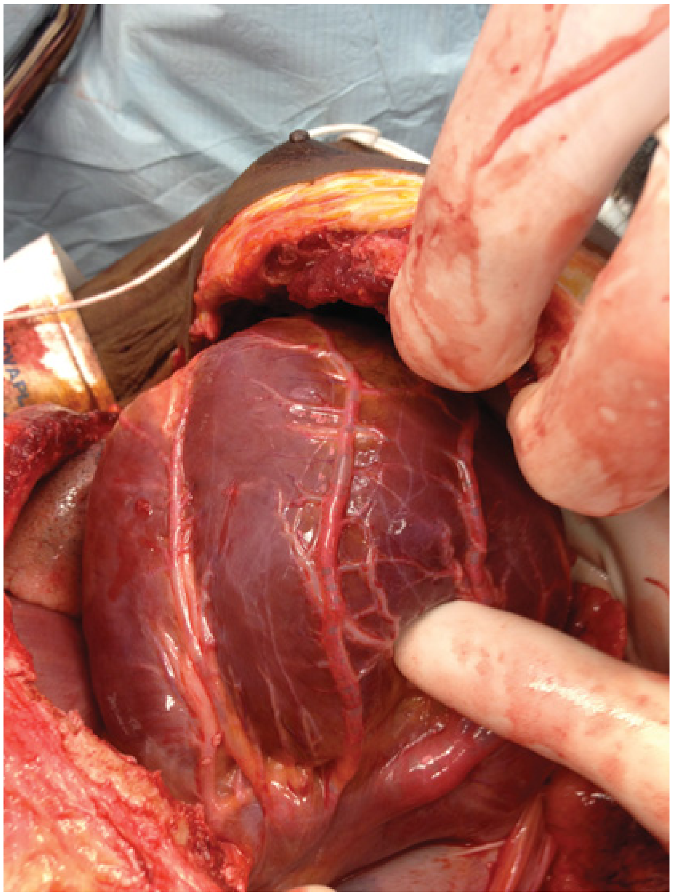


Figure 20.11 Air embolism with air bubbles in the coronary veins. This complication should be suspected in injuries to the low-pressure cardiac chambers, the lung, or major veins.

- Hilar occlusion should be considered in cases with severe bleeding from the hilum of the lung. This can be achieved with compression of the hilar structures between the index finger and the thumb, followed by application of a vascular clamp. Hilar twist should be avoided, as this maneuver can result in additional injury to the hilar structures.

Tips and Pitfalls

- The incision should not be lower than the fifth intercostal space! Below this level, the exposure of the upper part of the heart is poor and there is a risk of iatrogenic injury to the diaphragm.
- The incision should follow the curve of the ribs, with a direction toward the axilla, not straight down on the bed.
- Check for iatrogenic injury to the left internal mammary artery, particularly if the incision is too close to the sternum.
- Physicians lacking experience with this procedure may cross-clamp the esophagus, instead of the thoracic aorta, in patients with no pulse. Anatomically, the aorta is the first structure encountered after the vertebral body when advancing the fingers along the posterior wall of the thorax toward the spine. A nasogastric tube in the esophagus may help identify the structures.
- Avoid excessive mobilization of the thoracic aorta during cross-clamp. Avulsion of intercostal arteries causes severe bleeding, which is difficult to control.

Chapter

21

Resuscitative Endovascular Occlusion of the Aorta (REBOA)

Elizabeth R. Benjamin and Kazuhide Matsushima

General Principles

- REBOA is an endovascular occlusion balloon, inserted through the femoral artery, designed to occlude the aorta in the setting of severe abdominal or pelvic hemorrhage (Figure 21.1).

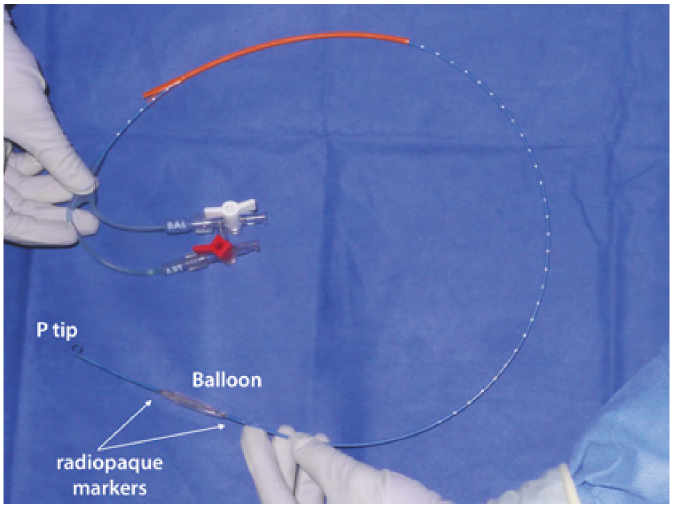


Figure 21.1 The REBOA catheter. Pictured is a common commercially available catheter (ER-REBOA™) with an atraumatic p-tip, radio-opaque markers above and below the compliant balloon, cm markings for precise placement, and an arterial port for proximal pressure monitoring.

- REBOA is a resuscitative adjunct that, in the appropriate setting, can delay exsanguination and provide support during transition to definitive operative care.
- Although most commonly described for hemorrhage due to trauma, REBOA may also play a role in resuscitation during obstetric catastrophes or bleeding from nontraumatic sources such as gastrointestinal or hepatic parenchymal hemorrhage.
- For the purposes of REBOA insertion, the aorta is divided into three anatomical zones (Figure 21.2):

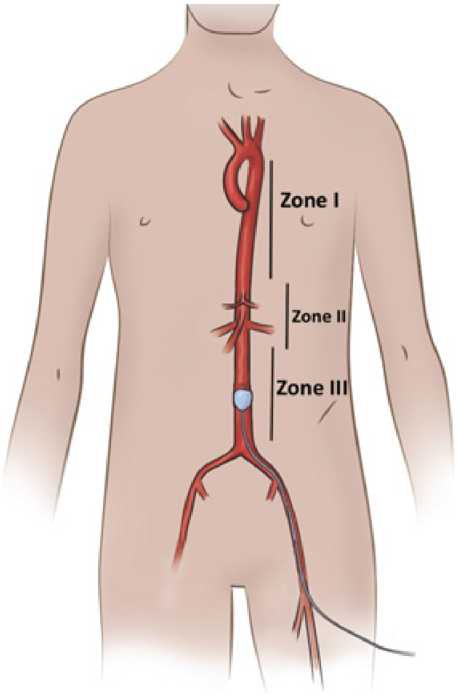


Figure 21.2 The zones of occlusion include zone I, above the level of the diaphragm, distal to the left subclavian artery, ideal for abdominal hemorrhage, and zone III, below the renal arteries and above the bifurcation, ideal for pelvic and perineal hemorrhage. Zone II is perivisceral and inflation in this zone is not recommended.

  - Zone I: Distal to the left subclavian artery, above the diaphragm
  - Zone II: From the celiac artery to renal arteries
  - Zone III: Distal to the renal arteries to above the abdominal aorta bifurcation

- For bleeding control from the upper abdomen, the catheter balloon is inflated in zone I (external landmark is the mid-sternum). For bleeding control in the pelvis, the balloon is inflated in zone III. Inflation of the balloon is not recommended in zone II.
- The rate-limiting step in REBOA placement is arterial access and, for this reason, if potential need for aortic occlusion is anticipated, access can be secured early using a femoral arterial line or a 5-F sheath. For example, in cases of placenta accreta, preoperative placement of a minimally invasive small-gauge femoral arterial line, can potentially save time, allowing for rapid upsize rather than de novo placement of access for REBOA insertion in the event of acute hemorrhage.
- REBOA can be placed in the Emergency Department, ICU, or operating room by a trained provider.
- REBOA is a *temporary* occlusion device and prolonged inflation can lead to visceral and/or limb ischemia and should be avoided at all cost. REBOA should be considered and inflated only in the setting of available surgical providers to address the immediate hemorrhage control needs of the patient. Access to providers to address potential complications of catheter placement, including peripheral and central arterial injury, is also a necessity.
- REBOA is contraindicated for thoracic or neck bleeding. Whenever possible, thoracic imaging such as a chest X-ray should be obtained prior to REBOA placement to rule out a thoracic source of hemorrhage that may be exacerbated by aortic balloon occlusion.

Technique

- The common femoral artery can be accessed at about 2 cm below the inguinal ligament, halfway between the pubic symphysis and the anterior superior iliac spine. The artery is accessed either percutaneously with ultrasound guidance (Figure 21.3 A,B) or via an open groin dissection (Figure 21.4 A,B).

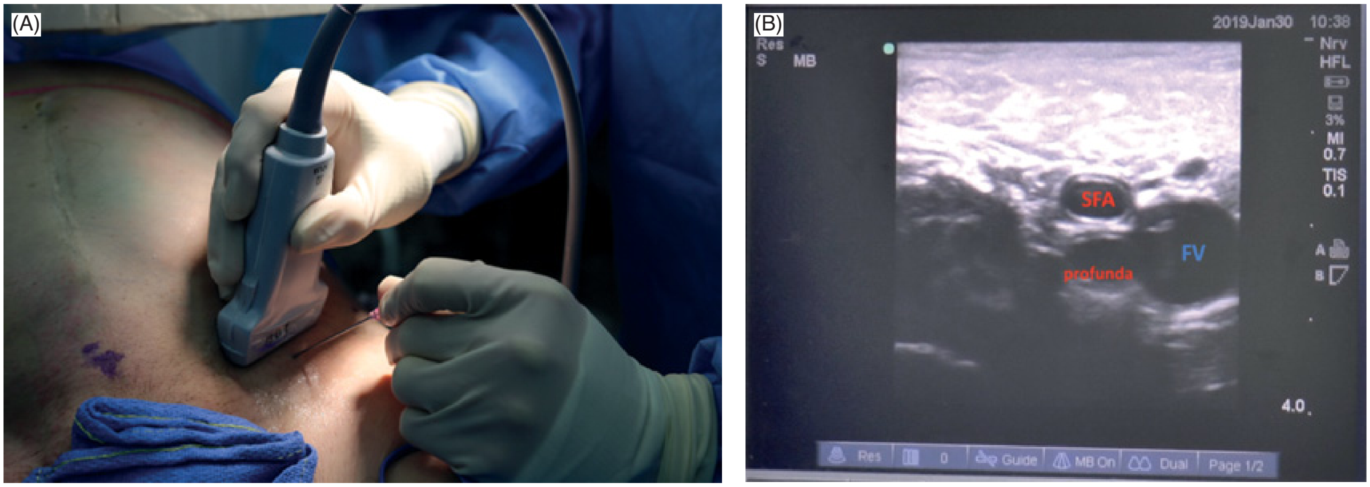


Figure 21.3 A,B Ultrasound is used in placement of the femoral artery access catheter in order to confirm placement above the bifurcation and below the inguinal ligament in the common femoral artery. The femoral artery bifurcation (b) is visualized next to the femoral vein (FV) and the ultrasound is then moved cranially to visualize the common femoral artery. Placement of the REBOA catheter in the superficial femoral artery (SFA) significantly increases complications of limb ischemia and arterial injury.

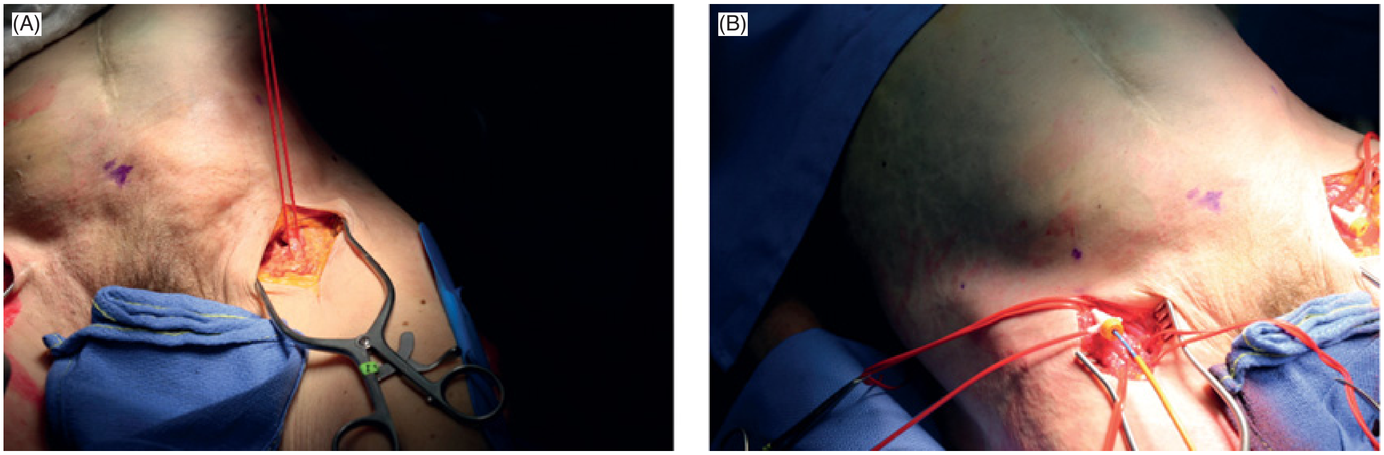


Figure 21.4 A,B If part of the provider skillset, access can be achieved using an open technique, exposing the common femoral artery for access (A). The ideal access point is approximately two fingerbreadths below the inguinal ligament or approximately 1–2 cm above the femoral artery bifurcation. The REBOA catheter can be placed through the sheath directly into the artery (B).

- Initial access options include an 18-gauge femoral arterial catheter, which may later be upsized to a 7-F sheath, a 5-F sheath that can be used for arterial monitoring and also upsized, or immediate placement of a 7-F sheath. Prior to initiating a REBOA program, the sequence options should be protocolized and materials bundled in an easily accessible kit, as not all wires and catheters are complimentary (Figure 21.5 A,B, Figure 21.6).

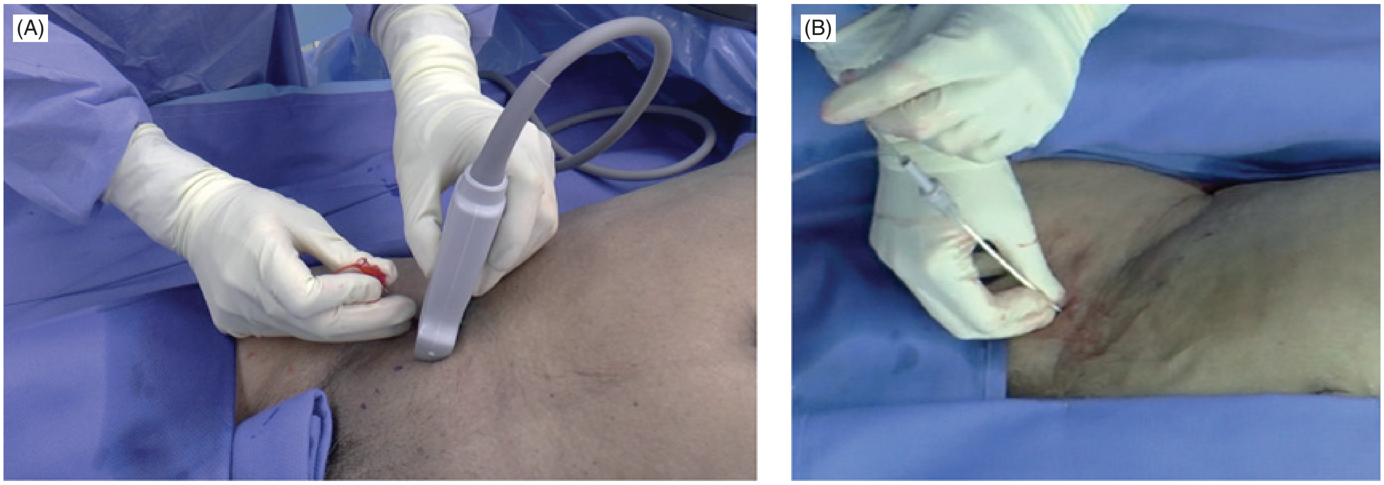


Figure 21.5 A,B Femoral artery access using a micropuncture needle (A), followed by placement of a 5-F sheath (B).

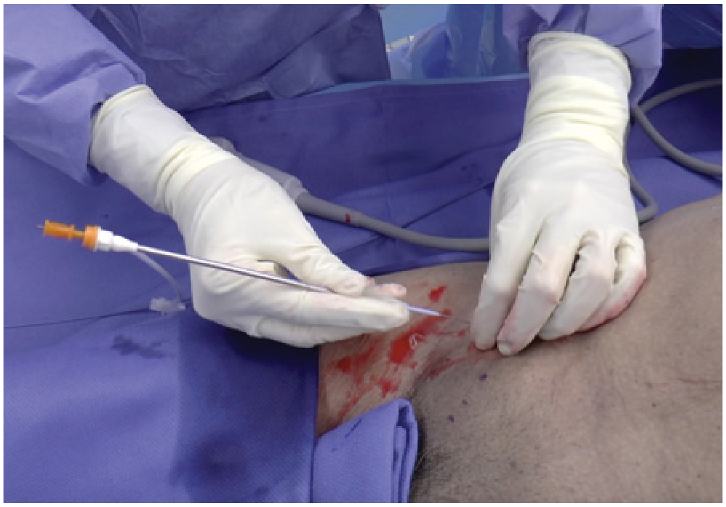


Figure 21.6 The 5-F sheath can be upsized to a 7-F sheath for REBOA access.

- Once the 7-F sheath is in place, this should be adequately secured.
- The REBOA catheter is prepared using the following steps:
  - o Residual air is removed from the balloon and the peel-away sheath is spiraled carefully over the balloon and p-tip (Figure 21.7 A,B).
  - o The arterial port is flushed with saline.
  - o Using external landmarks, distance to zone I occlusion is approximated by measuring the distance from the sheath to the balloon at the mid sternum. The external landmark for zone III occlusion is less well defined, but balloon placement above the level of the umbilicus most reliably approximates inflation above the iliac bifurcation. X-ray confirmation of balloon placement is recommended prior to zone III inflation, given the short landing zone and variability of umbilical measurements with body habitus (Figure 21.8).

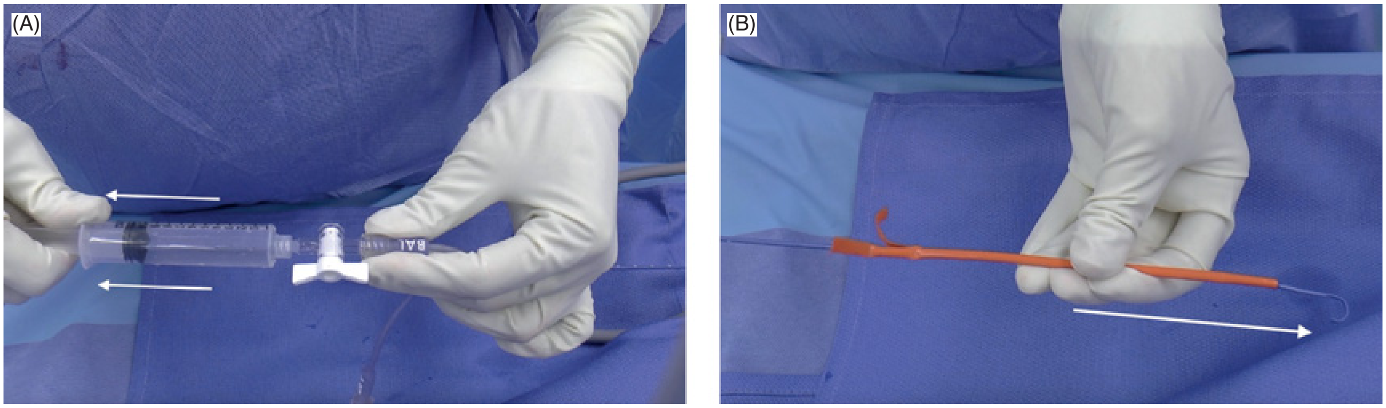


Figure 21.7 A,B The balloon is emptied of any residual air (A) to allow easy passage into the peel-away sheath (B).

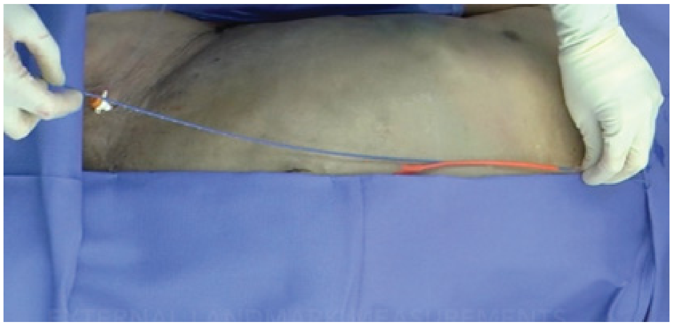


Figure 21.8 External landmarks can be used to approximate the distance to zone I occlusion.

- The peel-away sheath is inserted less than 1 cm into the 7-F sheath, and the catheter is advanced until the balloon is distal to the sheath valve, after which point the peel away is removed. The arterial port is flushed and connected to an arterial monitoring device (Figure 21.9 A–C).

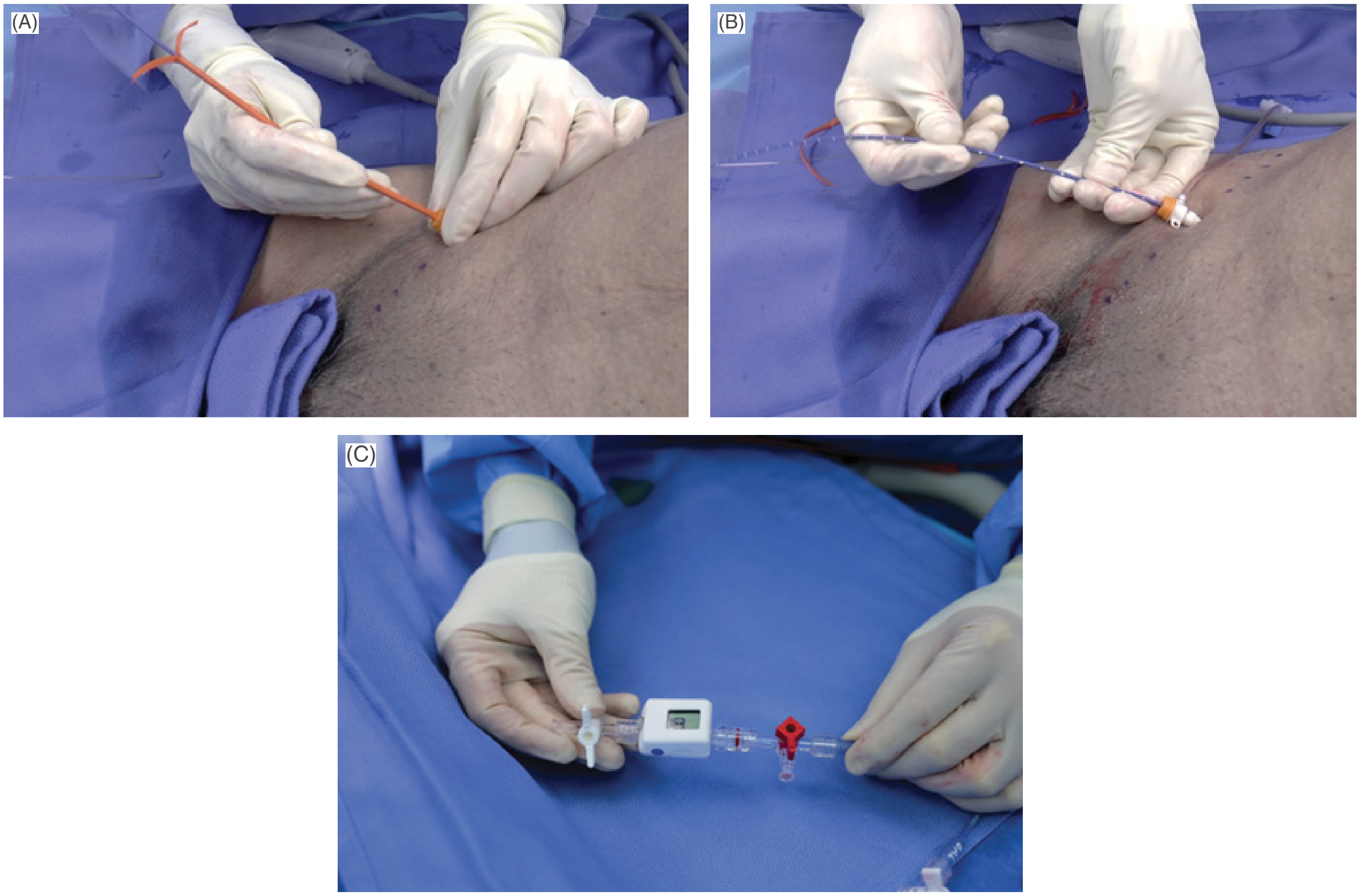


Figure 21.9 A–C The catheter, protected by the peel-away sheath, is inserted through the 7-F femoral artery sheath (A). Note that the peel-away sheath can enter the 7-F sheath only less than 1 cm. The purpose of the peel-away is to straighten the p-tip, open the sheath valve, and allow safe, atraumatic passage of the balloon into the arterial lumen (B). A portable digital pressure monitor may be used on the arterial port if a traditional arterial monitoring device is not readily available (C).

- Once the catheter is at the desired position, time and resource permitting, an X-ray is obtained to confirm placement (Figure 21.10).

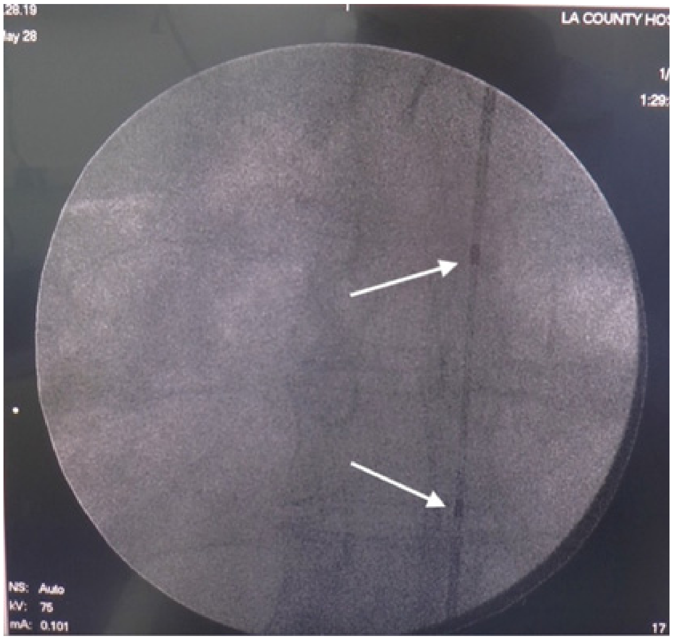


Figure 21.10 Radio-opaque markers on the ER-REBOA™ catheter can be used to confirm placement prior to balloon inflation.

- The balloon is then inflated with a 50% strength contrast. The volume needed for inflation differs based on catheter type and aortic diameter. Occlusion volume can be determined using fluoroscopy, by haptic feedback, loss of contralateral pulse, or loss of arterial waveform if an arterial pressure monitor is present on the contralateral side below the level of occlusion.
- Balloon morphology is confirmed by X-ray, taking care to evaluate for over- or under-inflation (Figure 21.11 A,B).
- Once placement is confirmed, the catheter is secured in place.
- Proceed immediately to definitive hemorrhage control.

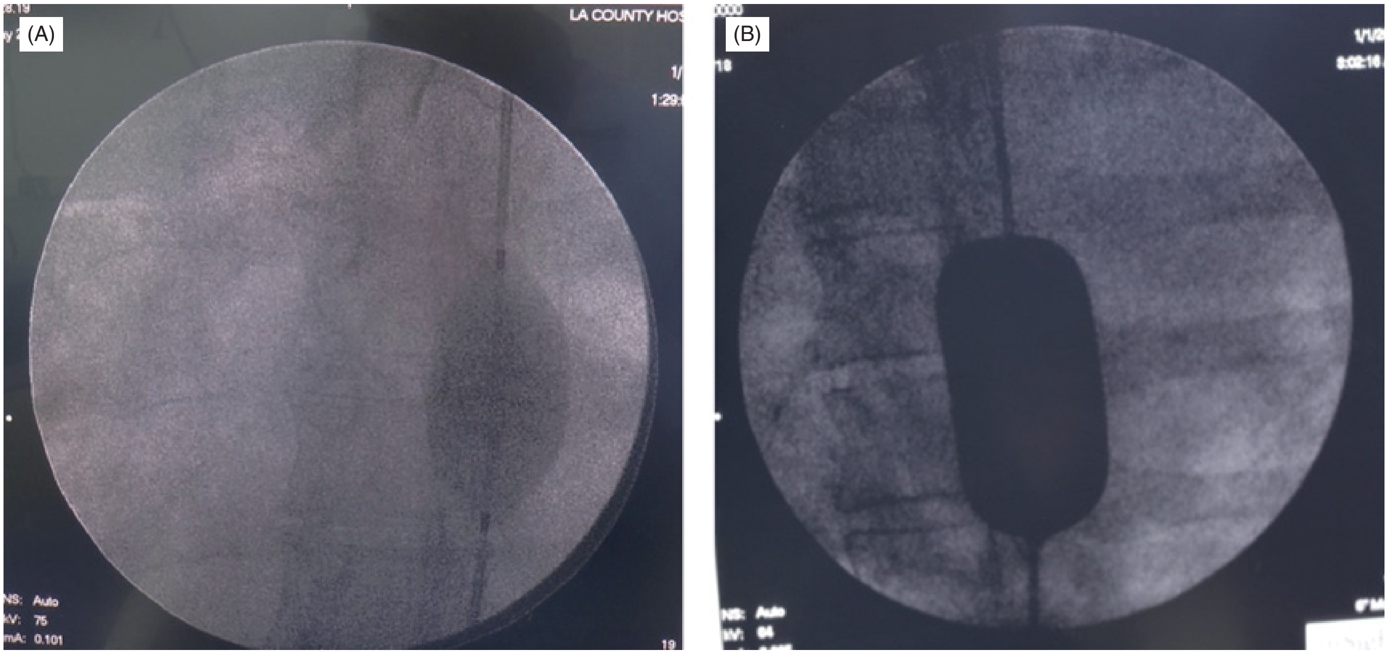


Figure 21.11 A,B The balloon is inflated with 50% strength contrast and balloon morphology and placement is confirmed with X-ray (A). Overinflation of the balloon can lead to aortic intimal damage or balloon rupture (B). Note the flattened top of the balloon due to overinflation.

REBOA and Sheath Removal

- The REBOA catheter and sheath should be removed as soon as possible after acute hemorrhagic event. Additional dwell time increases potential complications.
- The REBOA catheter should be completely deflated prior to removal.
- Aspirate from the sheath side port to confirm lack of clot at the end of the sheath.
- Remove sheath and hold pressure for 30 minutes or perform an open groin dissection and primarily close the arteriotomy under direct visualization.
- If the sheath must remain in place temporarily due to extreme coagulopathy, run a crystalloid solution through the lumen using a pressure bag to decrease the risk of clot formation.
- Continue q1hr pulse checks for 24 hours post sheath removal. Complications include but are not limited to bowel ischemia, acute kidney injury, arterial thrombosis, distal embolism, false aneurysm, and extremity compartment syndrome.
- Obtain a vascular ultrasound at 24 hours to evaluate for pseudoaneurysm at the insertion site.

Tips and Pitfalls

- Early common femoral artery access either with a femoral arterial line or 5-F sheath can decrease the time to occlusion in the event of severe hemorrhage.
- Zone of occlusion is determined based on location of hemorrhage. In the absence of identification of hemorrhagic location, zone I occlusion is the default inflation zone; however, prolonged zone I occlusion can result in life- and limb-threatening visceral and extremity ischemia (Figure 21.12).

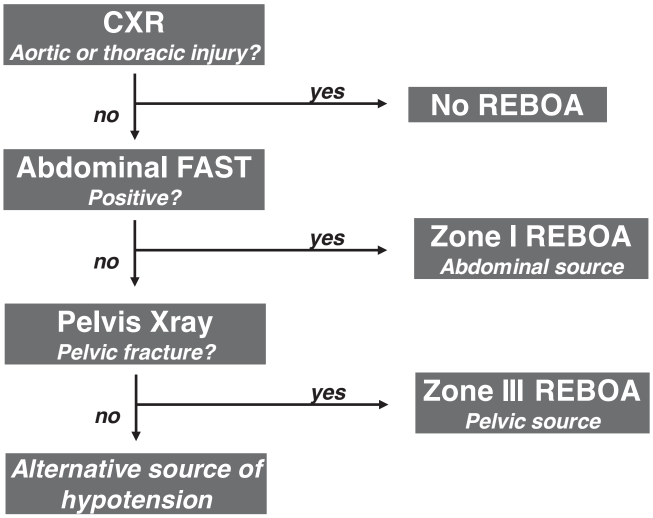


Figure 21.12 Algorithm for REBOA placement.

- The significant risk of REBOA placement should be weighed against the risk of ongoing uncontrolled hemorrhage, and REBOA should be considered only in the peri-arrest patient.
- REBOA inflation increases intrathoracic aortic pressure and therefore should not be considered in patients with intrathoracic or neck hemorrhage. In addition, REBOA has no therapeutic role and thus does not replace the role of therapeutic emergency department thoracotomy.
- Partial REBOA is a technique in which the degree of aortic occlusion is titrated to resuscitative need. This is an active process that requires close monitoring of the pressures above and below the balloon. Partial REBOA is most effectively delivered with the placement of a contralateral femoral arterial monitor and active ongoing balloon titration and hemorrhage resuscitation. This technique potentially extends the tolerated duration of inflation by decreasing ischemia time and increasing perfusion to tissue distal to the balloon placement.
- REBOA can provide an alternative to open occlusion of the aorta in appropriate cases. Care must be taken to access the femoral artery at the level of the common and not the superficial femoral artery. Despite the smaller access sheath sizes in contemporary catheters, local complications at the insertion site are common.
- Pulses distal to the catheter insertion site should be monitored every hour while the sheath is in place and for the 24 hours following removal. Clot formation resulting in embolic or thrombotic complications, dissection flaps, and pseudoaneurysm are all potential complications following sheath placement.
- Routine evaluation of the insertion site for pseudoaneurysm formation 24 hours after sheath removal is recommended.
- The REBOA catheter and sheath should be removed as soon as possible once the acute hemorrhagic event has been addressed. Continued use of the sheath or catheter is not recommended and is associated with increased risk of complication, including limb loss.
- Formal REBOA training is recommended for all providers responsible for determining candidacy and placing an endovascular aortic occlusion balloon.

Chapter

22

Diagnostic Peritoneal Aspiration

Demetrios Demetriades and Damon Clark

General Principles

- Diagnostic peritoneal aspiration (DPA) involves the insertion of a needle or a catheter in the peritoneal cavity and aspiration of any blood or other fluid. Diagnostic peritoneal lavage (DPL) includes infusion of normal saline, lavage of the cavity, and macroscopic and microscopic evaluation of the returned fluid.
- DPA and DPL have largely been replaced by the trauma ultrasound (FAST exam) and CT scan. However, DPA may have a useful role in the evaluation of the abdomen in a hemodynamically unstable patient, if the FAST exam is not definitive or not available.
- The DPA is as sensitive as DPL in identifying clinically significant intraperitoneal bleeding. For this reason, DPL has largely been abandoned.
- The procedure is most commonly performed with the percutaneous Seldinger technique. The open technique is preferred in patients with advanced pregnancy to avoid inadvertent injury.
- DPA is contraindicated in patients with previous abdominal operations or coagulopathy. Morbid obesity is a relative contraindication.

Equipment

There are commercially available kits, which usually include:

- 5 ml syringe with 1% lidocaine with epinephrine
- Chlorhexidine or betadine skin preparation
- Scalpel
- 5 or 10 ml syringe with 18 G needle
- Guidewire
- Peritoneal catheter (Figure 22.1 A,B)

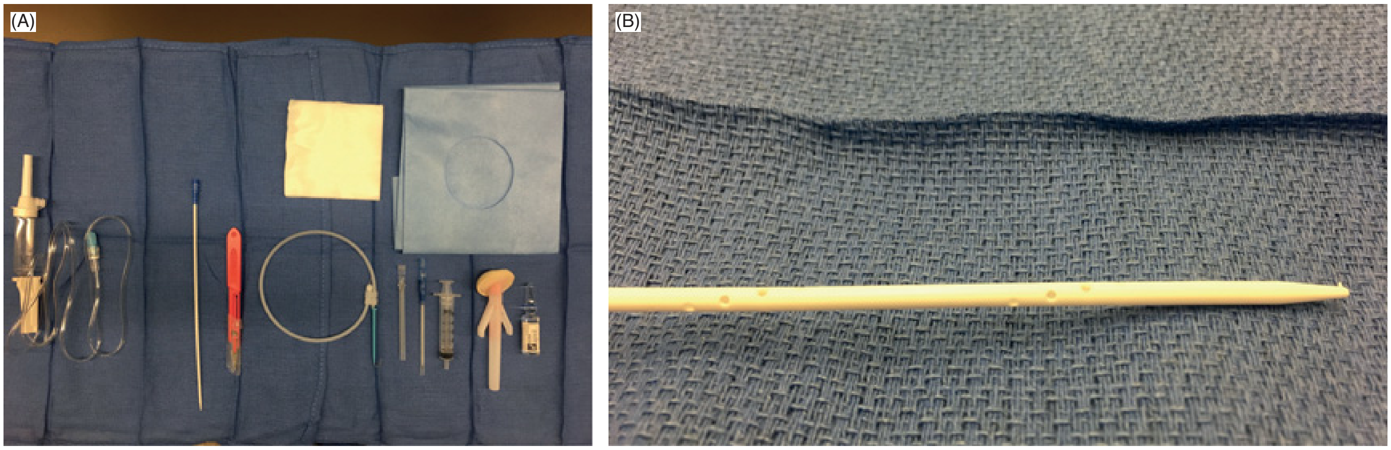


Figure 22.1 A,B Standard DPA kits generally include lidocaine 1%, scalpel, 18 g and 20 g needle with angiocatheter, 10 ml syringe, guidewire, and peritoneal catheter (A). Close up of peritoneal dialysis catheter showing the multiple side holes (B).

Percutaneous Seldinger Technique

- A Foley catheter should be inserted before the procedure to decompress the bladder and avoid injury to the bladder.
- Sterile preparation and draping of the anterior abdomen.
- Make a 0.5 cm vertical skin incision about 1–2 fingerbreadths below the umbilicus. A supraumbilical incision is preferred in patients with severe pelvic fractures.
- A needle attached to a 5 or 10 ml syringe is inserted into the peritoneum, with a slight angle, pointing towards the pelvis. Two “pops” should be felt during insertion through the fascia and the peritoneum.
- If aspiration on the needle gives gross blood (10 ml or more), the investigation is positive and the procedure is terminated.
- If the needle aspiration is negative, the syringe is disconnected from the needle and the guidewire is inserted through the needle, in a direction towards the pelvis. No

Open Technique for DPA

The open technique is preferred in patients with advanced pregnancy to avoid inadvertent injury to the uterus or in patients with severe pelvic fractures.

Equipment

- The above equipment for DPA
- Two Kocher clamps
- Needle driver
- Scissors

Technique

- Similar sterile precautions as with the closed technique.
- A 2 cm incision is performed about two fingerbreadths below the umbilicus. The incision is placed above the umbilicus in advanced pregnancy or severe pelvic fractures.
- The subcutaneous tissues are dissected down to the fascia with a curved hemostat.
- The fascia is grasped and lifted with two Kocher clamps. The fascia is opened with a scalpel, and the underlying peritoneum is identified and incised with scissors.
- A purse string or figure of eight suture (0-vicryl) is placed but not tied, on the fascia opening.
- The peritoneal dialysis catheter is inserted under direct vision into the peritoneal cavity, with a slight angle toward the pelvis and along to the anterior abdominal wall.
- Connect a 5 or 10 ml syringe to the catheter and aspirate (Figure 22.4).
- After completion of the aspiration, the catheter is removed and the fascia is closed with the previously placed purse-string or figure of eight suture.
- The skin is closed with staples or sutures.

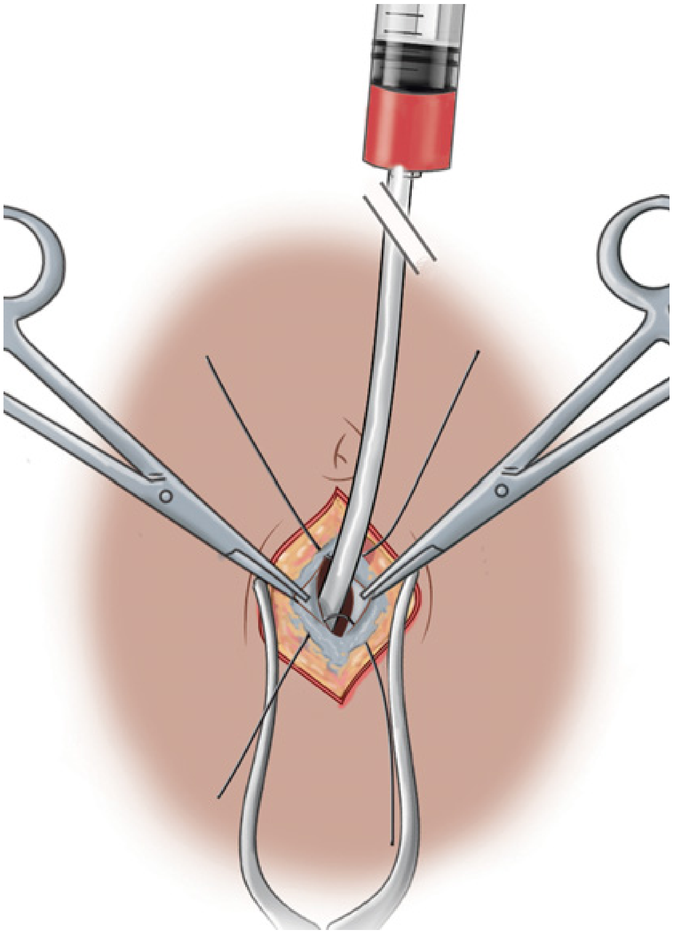


Figure 22.4 Open technique for DPA. A 2 cm incision is performed about two fingerbreadths below the umbilicus. The subcutaneous tissues are dissected down to the fascia. The fascia is grasped and lifted with two Kocher clamps. The fascia is opened with a scalpel and the underlying peritoneum is identified and incised with scissors. Two stay sutures are placed and the catheter is inserted under direct vision into the peritoneal cavity, with a slight angle toward the pelvis and along to the anterior abdominal wall. A syringe is connected to the catheter and aspiration is performed.

Tips and Pitfalls

- "Feel" for the "two pops" during insertion of the needle through the fascia and peritoneum.
- Avoid any force during insertion of the guidewire. If the wire cannot slide easily, most likely the tip is not in the peritoneal cavity. Withdraw and reinsert the needle.
- Although normally there is some resistance during the insertion of the peritoneal catheter, do not use excessive force. If excessive resistance is met during insertion, remove and reinsert the guidewire.
- Technical problems, such as insertion of the needle or the catheter into an abdominal wall or pelvic hematoma can give false positive DPA.
- Inadvertent insertion of the catheter in the extraperitoneal space can result in false-negative results.
- DPA will not identify retroperitoneal bleeding.

Chapter

23

Tourniquet Application for Extremity Bleeding Control

Joelle Getrajdman and Kenji Inaba

General Principles

- Hemorrhage is the leading cause of preventable death in trauma. Immediate control of visible external bleeding is critical.
- Direct pressure and/or wound packing remain the mainstay for hemorrhage control of extremity and junctional (neck, axilla, and groin) trauma.
- Several local hemostatic agents are available.
- If direct pressure is not possible or effective, the use of a tourniquet for extremity bleeding may be life-saving.
- The low complication and high success rates of tourniquets for extremity bleeding have been well established in the military medical system. Their use is becoming increasingly popular in the civilian sector.

Special Surgical Instruments

- Universal precautions should always be used.
- Several types of tourniquets for extremity trauma are available and approved by the Committee on Tactical Combat Casualty Care.
- While windlass tourniquets may be used in the pre- and in-hospital settings, pneumatic tourniquets are most frequently used intraoperatively.

Procedure for Extremity Tourniquet Application

1. Place the tourniquet around the limb and weave the strap through the buckle (Figure 23.1). Alternatively, in tourniquets that come preassembled, they can be slipped over the limb. If possible, clothing should be removed prior to placement. If this is not possible, avoid placing the tourniquet over bulky clothing or pockets.

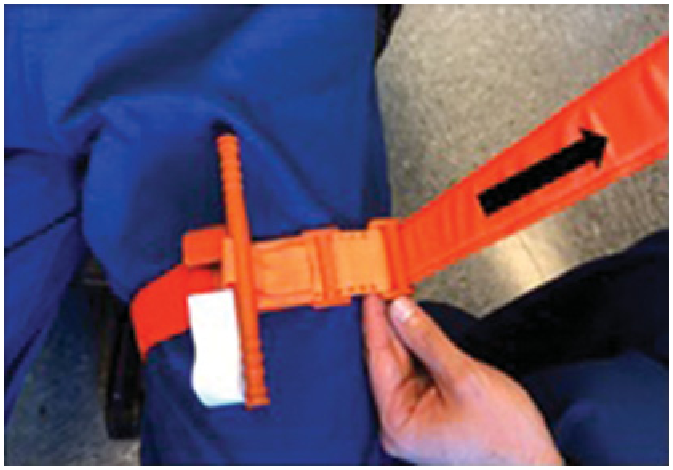


Figure 23.1 The tourniquet is placed over the extremity with the strap woven through the buckle.

2. Tighten the tourniquet snugly down onto the limb, 2–3 inches proximal to the injury. Avoid placement over a joint (Figure 23.2). Remember: "high and tight."

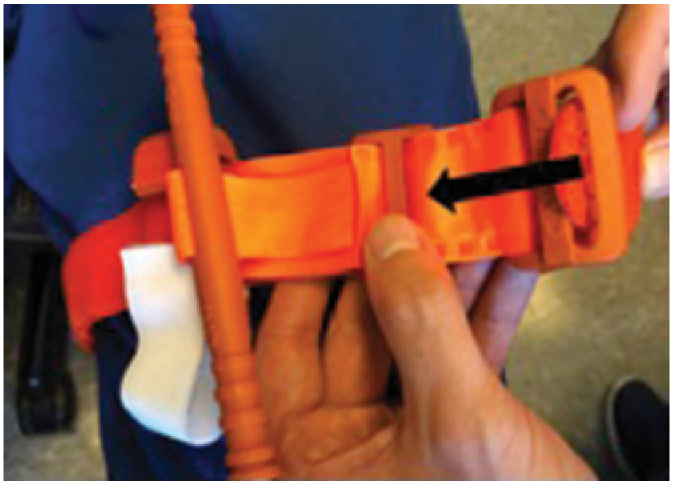


Figure 23.2 The tourniquet is tightened snugly onto the limb.

3. Wrap the excess strap around the extremity and secure using the velcro strap (Figure 23.3). Do not pass the retention device so as not to block the bar from turning.

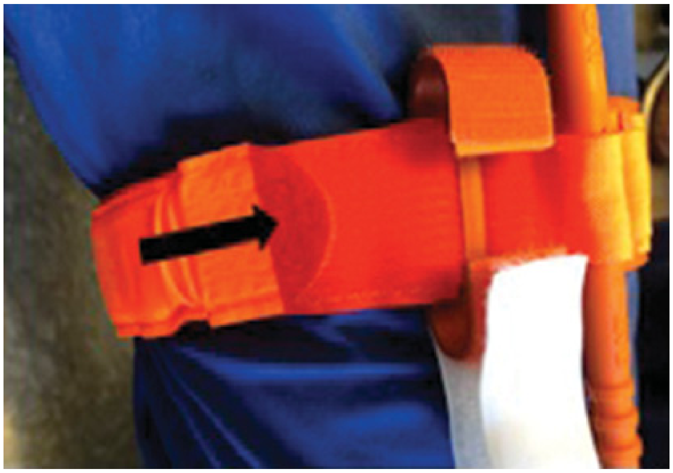


Figure 23.3 The excess strap is wrapped around the limb and secured with velcro.

4. Turn the bar until the bleeding stops (Figure 23.4). This may take multiple turns. The bar may be turned in either direction.

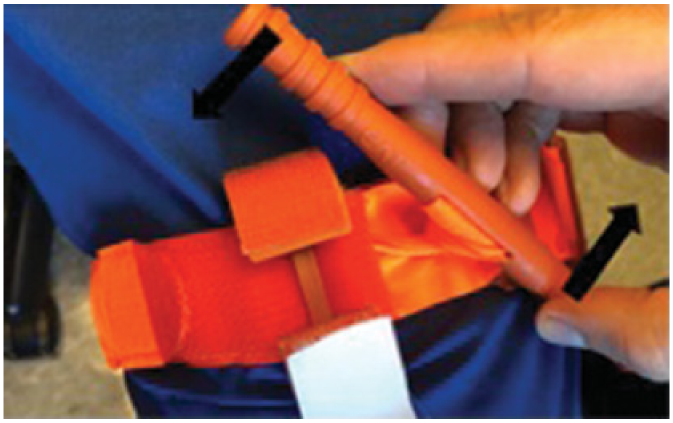


Figure 23.4 The bar is turned until the bleeding stops.

5. The bar is then locked under the retention clip (Figure 23.5).

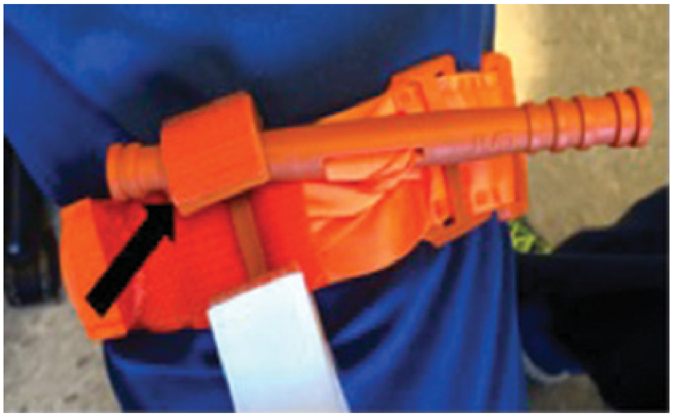


Figure 23.5 The bar is locked under the retention clip.

6. Place the velcro strap across the clip to prevent the rod from being displaced. Note the application time directly on the tourniquet (Figure 23.6). Do not remove the tourniquet until the patient has reached definitive medical care.

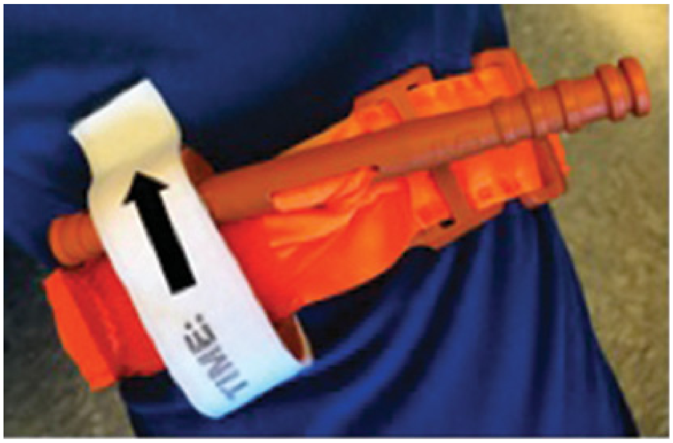


Figure 23.6 The velcro strap is placed on the clip to prevent the rod from being dislodged. The time of placement is noted on the velcro strap.

Junctional Hemorrhage

- Junctional hemorrhage from the neck, axilla, or groin, while also amenable to direct pressure and/or packing, often presents a greater challenge than extremity hemorrhage.
- If direct pressure and/or packing is not effective, the use of a junctional tourniquet, Foley catheter balloon tamponade, or another hemostatic device may aid in junctional hemorrhage control.

Tips and Pitfalls

- There may be multiple sources of bleeding in a single extremity; the tourniquet should be placed high and tight above the most proximal source. Incorrect tourniquet placement below the level of the injury will not result in cessation of bleeding and will worsen distal extremity ischemia (Figure 23.7).
- Tourniquet placement over a joint or pockets should be avoided. Preferably they are used directly on the skin.
- Tightening of the tourniquet until cessation of both arterial and venous bleeding is achieved is crucial. If bleeding does not stop, apply a second tourniquet above the first (Figure 23.8 A,B).
- An inadequately tightened tourniquet may worsen distal venous bleeding.
- Correct tourniquet placement will be very painful for the patient. Pain does not indicate incorrect tourniquet placement.

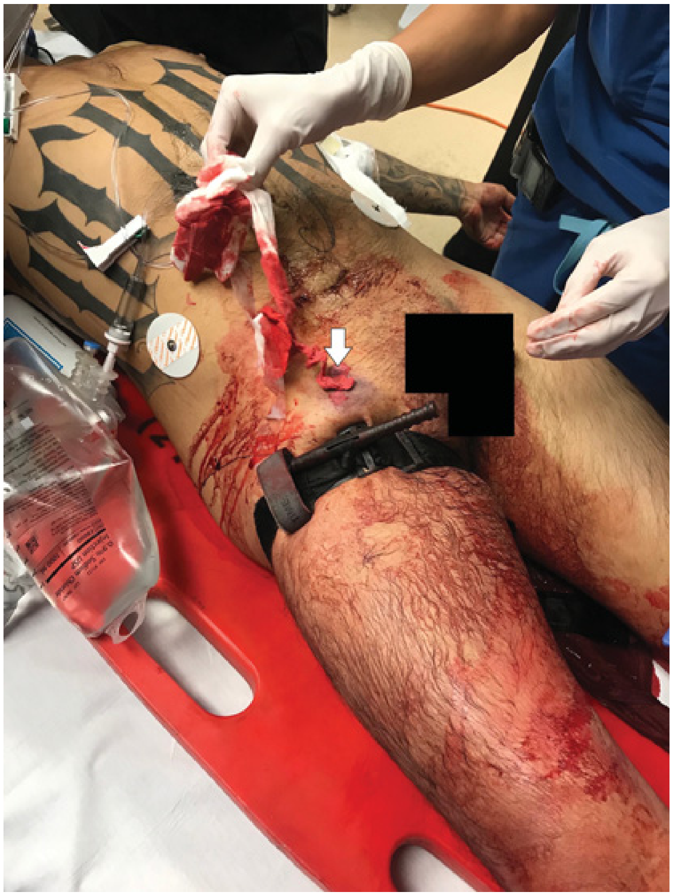

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Figure 23.7 Incorrect placement of tourniquet below the level of a gunshot wound to the right groin (arrow).

- Junctional tourniquets have been developed but are not uniformly available for widespread use.
- On admission to the emergency room, check if the tourniquet is indeed needed by loosening the device. Often the tourniquet is not needed and can be promptly removed.
- Document the time of tourniquet application.
- Prolonged tourniquet application may result in extremity compartment syndrome after reperfusion.

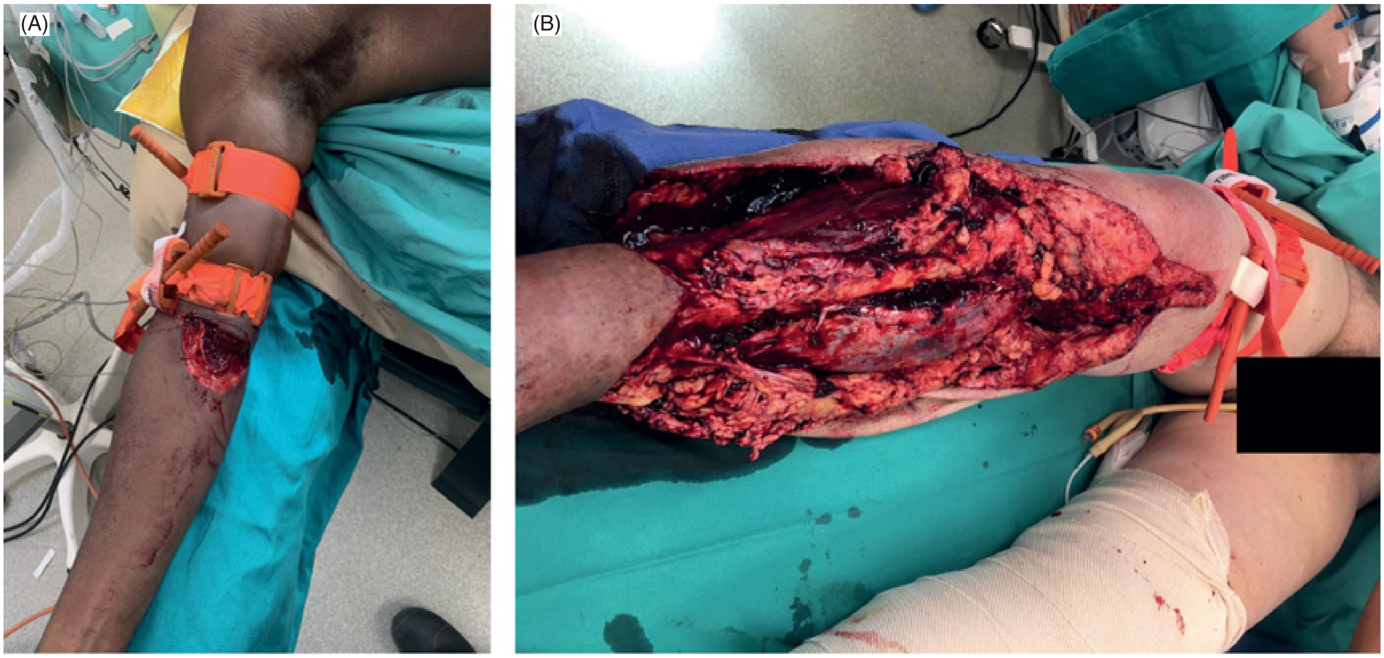

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Figure 23.8 A,B When cessation of bleeding is not controlled with a single tourniquet, a second may be added above the level of the first. Stab wound to the right antecubital fossa with arterial bleeding (A). Mangled right thigh with severe bleeding following a motorcycle collision (B).

Chapter

24

Splinting

Carl R. Chudnofsky

General Principles

- Splints should be used to temporarily immobilize possible fractures and dislocations during the evaluation and management of life- and limb-threatening injuries.
- Immobilization decreases blood loss, minimizes the potential for further neurovascular injury, reduces pain, and may decrease the risk of fat emboli from long bone fractures.
- In most instances, properly applied splints provide short-term immobilization equal to that of casts and can be rapidly applied.
- Definitive fracture care should never take precedent over evaluation and management of the ABCs, hemorrhage control, or treatment of life-threatening injuries.

Equipment and Supplies

- Plaster of Paris is the most widely used material for emergency department splinting. Plaster rolls and sheets are available in a variety of setting times and widths (2-, 3-, 4-, or 6-inch widths).
- Prefabricated splint rolls (e.g., OCL, BSN Medical) have become popular among emergency clinicians. These splint rolls have 10 to 20 sheets of plaster enclosed between a thick layer of protective foam padding on one side and a thin layer of cloth on the other. Like custom-made splints, they are secured to the extremity with an elastic bandage.
- Prefabricated splint rolls are generally quicker to apply, but are more expensive and lack some of the versatility and custom fit qualities of custom-made plaster splints.
- Cast padding (e.g., Webril [Curity] or Specialist [Johnson & Johnson]) is placed under the splint to protect the skin and bony prominences.
- Elastic bandages are used to secure the splint in place. Elastic bandages are available in 2-, 3-, 4-, and 6-inch widths.
- Use cloth tape to prevent slippage of the elastic bandages, to line the cut edges of a bivalved cast, and to buddy-tape digits. Coban tape can be used in a similar manner and has the advantage of adhering only to itself.
- A utility knife, a #10 scalpel blade, or plaster/trauma scissors can be used to cut and shape dry plaster, and a large bucket or basin is used for wetting plaster.
- Protective equipment, including gown, gloves (vinyl or latex), and safety glasses, is recommended.

General Procedure of Custom Splint Construction and Application

Unless otherwise noted, the remainder of this chapter focuses on the construction and application of custom-made plaster splints commonly used to temporarily immobilize injured extremities during the initial evaluation and treatment of life- and limb-threatening injuries.

Patient Preparation

Carefully inspect and examine the involved extremity before splinting, and clearly document the presence of all skin lesions and soft tissue injuries. When open fractures or joints are to be immobilized, cover the soft-tissue defect with saline-moistened sterile gauze prior to splint application.

Padding

In the setting of severe trauma, when rapid temporary immobilization is required, it is easier and faster to place two or three layers of cast padding (the same diameter or slightly wider than the plaster splint) over the wet plaster rather than wrapping the cast past padding around the extremity. The cast padding should extend 2.5 to 5.0 cm beyond the ends of the splint so that it can be folded back over the splint to help create smooth, well-padded edges. When possible, place extra padding over areas of bony prominence, such as the radial condyle or the malleoli.

Plaster Preparation

The choice of plaster setting time depends on the nature of the injury and the expertise of the clinician. Use fast- or extra-fast-setting plaster when rapid hardening is desired to help maintain alignment of an acutely reduced fracture.

The ideal length and width of plaster depend on the body part to be splinted. The best way to estimate length is to lay the dry splint next to the area to be splinted. It is best to use a generous length because wet plaster shrinks slightly from its dry length. Also, if the wet splint is too long, the ends can be folded back easily. The plaster width varies according to the type of splint being made and the body part that is injured, but generally, it should be slightly greater than the diameter of the limb to be splinted. Specific recommendations regarding splint length and width are discussed in the sections describing individual splints.

The thickness of a splint depends on the size of the patient, the extremity that is injured, and the desired strength of the final product. In general, it is best to use the minimum number of layers necessary to achieve adequate strength. Thicker splints are heavier and more uncomfortable. It is also important to note that plaster thickness is a major determinant of the amount of heat given off during the setting process. More than 12 sheets of plaster create an increased risk of significant burns, especially when using extra-fast-drying plaster or using dipping water with a temperature greater than 24°C. *For an average-sized adult, splint upper extremities with 8 sheets of plaster and lower extremities with 12 to 15 sheets.* This layering usually gives the strength necessary for adequate immobilization while reducing the patient's discomfort and the risk of significant burns.

Splint Application

Completely submerge the dry splint in a bucket filled with fresh water around 24°C until the bubbling stops. Remove the splint and gently squeeze out excess water until the plaster has a wet and sloppy consistency. Place the splint on a hard table or countertop (a protective covering is recommended to prevent water or plaster damage) and smooth out the splint (with gloved hands) to remove any wrinkles and ensure uniform lamination of all layers. Lamination helps increase the final strength of the splint. Lay the previously measured cast padding over the splint (the cast padding should extend 2.5–5.0 cm beyond the ends of the splint) and place the padded split over the extremity, padded-side down (against the skin). An assistant may be required to hold the splint in place during positioning. Once the splint has been properly positioned over the extremity, fold back the end of the cast padding to create smooth, well-padded ends and secure the splint with an appropriately sized elastic bandage by wrapping in a distal-to-proximal direction. Finally, place the extremity in the desired position and mold the wet plaster to the contour of the extremity with only the palms of the hand. Finger indentations may cause ridges, which can produce pressure points.

After Care

Following splint application, elevate the extremity (if possible) to reduce swelling and frequently check the injured extremity for adequate perfusion. Extremity color, temperature, pulses, and capillary refill should be reevaluated every 15 to 30 minutes and the results documented in the medical record.

Upper Extremity Splints

Long Arm Splints

Long Arm Posterior Splint

(Figure 24.1 A,B)

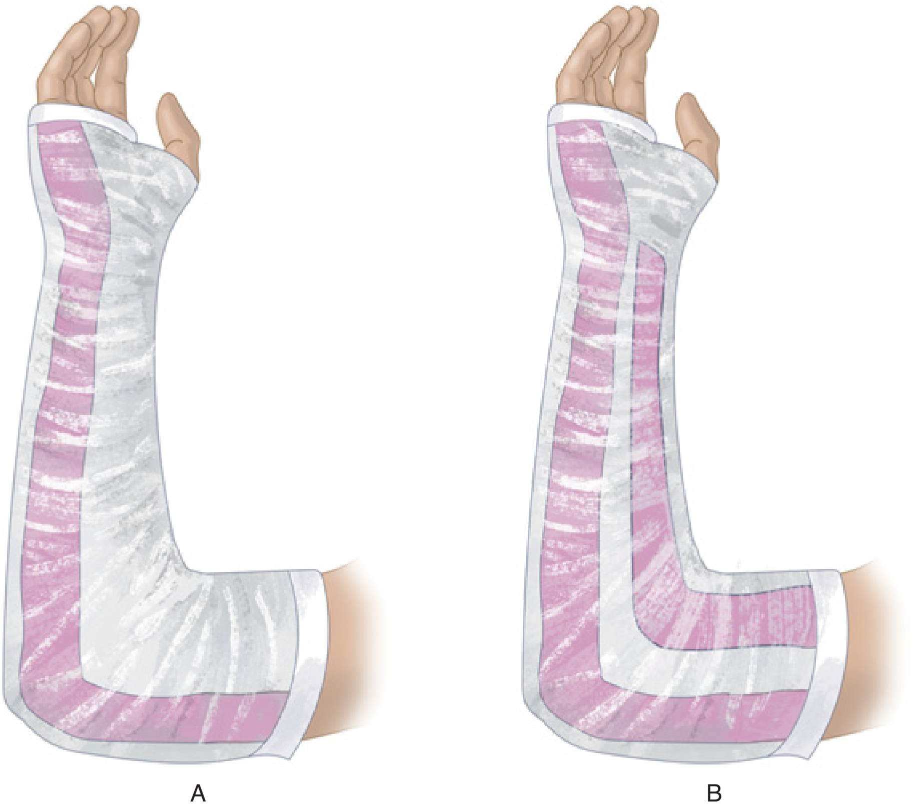


Figure 24.1 A,B Long arm posterior splint. Extend the splint from the posterior aspect of the humerus to the elbow and then along the ulnar aspect of the forearm to the distal metacarpals. Flex the elbow to 90 degrees, maintain the forearm in the neutral (thumb-up) position, and place the wrist in a neutral or slightly extended (10–20 degree) position (A). Long arm anterior splint. An anterior splint that mirrors the posterior splint may be used to increase stability and prevent supination and pronation. An anterior splint is never used alone (B).

Indications. Use a long arm posterior splint to immobilize injuries to the elbow and proximal end of the forearm. It completely eliminates flexion and extension of the elbow but does not entirely prevent pronation and supination of the forearm. Therefore, it is not recommended for immobilization of complex or unstable distal forearm fractures unless used in conjunction with a long arm anterior splint (see later in this section).

Construction. Construct a long arm posterior splint with 8 to 10 layers of 4- or 6-inch-wide plaster. Start the splint on the posterior aspect of the proximal end of the arm. Extend it down the arm to the elbow and then along the ulnar aspect of the forearm and hand to the level of the metacarpophalangeal (MCP) joints. Cut a small notch on each side of the splint at the elbow to allow the plaster to bend smoothly when the elbow is flexed to 90 degrees.

Application. Pad the wet splint as described previously. Place extra padding over the olecranon to prevent pressure injury. Position the arm with the elbow flexed to 90 degrees, the forearm neutral (thumb upward), and the wrist neutral or slightly extended (10 to 20 degrees). Ask an assistant to hold the wet splint in place, particularly when applying both a posterior and an anterior splint. Once the splint has been properly positioned, fold the sides of the splint up to create a gutter configuration. Next, fold the ends of the cast padding back and secure the splint in place with 2-, 3-, or 4-inch elastic bandages. Once secure, carefully mold the plaster around the extremity with the palms of the hand.

Long Arm Anterior Splint

Indications. A long arm anterior splint is never used alone but, rather, as an adjunct to a long arm posterior splint to improve immobilization by increasing stability and preventing pronation and supination of the forearm.

Construction. Construct a long arm anterior splint in the same manner as described for a long arm posterior splint. It mirrors the posterior splint by running down the anterior aspect of the arm to the antecubital fossa, where it continues along the radial aspect of the forearm to the distal end of the radius.

Application. When using both an anterior and a posterior long arm splint, have an assistant available to hold the wet splint in place. Place the padded anterior splint first and then position the posterior splint. Once both splints have been properly positioned, fold the sides of the splint up to create a gutter configuration. Next, fold the ends of the cast padding back and secure the splint in place with 2-, 3-, or 4-inch elastic bandages. Once secure, carefully mold the plaster around the extremity with the palms of the hand.

Double Sugar-Tong Splint

(Figure 24.2)

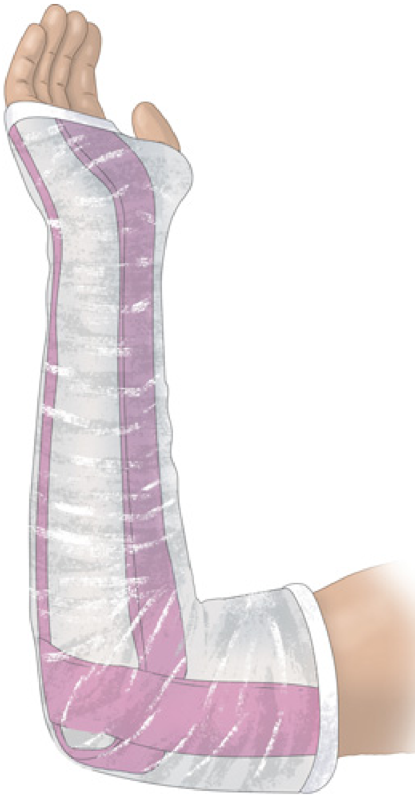


Figure 24.2 Double sugar-tong splint. Apply the forearm portion of the double sugar-tong splint first. Begin the splint at the metacarpal heads on the dorsum of the hand, and then extend it along the dorsal surface of the forearm and around the elbow. Continue along the volar surface of the forearm and stop at the level of the metacarpophalangeal joints. Begin the arm portion on the medial aspect of the proximal part of the arm, and then run it down over the forearm splint and around the elbow. Continue up the lateral aspect of the arm (once again going over the forearm splint) until it reaches the starting point. Keep the elbow flexed at 90 degrees, the forearm in the neutral (thumb-up) position, and the wrist in a neutral or slightly extended (10–20 degree) position.

Indications. A double sugar-tong splint can be used as an alternative to a long arm anterior and posterior splint to immobilize injuries to the elbow and forearm when prevention of pronation and supination of the forearm is desired.

Construction. The splint consists of two separate pieces of plaster, a forearm splint and an arm splint. Construct each piece with eight layers of 3- or 4-inch plaster. The forearm portion of the splint runs from the metacarpal heads on the dorsum of the hand along the dorsal surface of the forearm around the elbow. It continues along the volar surface of the forearm to the palm of the hand and stops at the level of the MCP joints. The arm portion of the splint begins on the anterior aspect of the proximal end of the humerus. It runs down the arm over the forearm splint and around the elbow. It then continues up the posterior aspect of the arm until it reaches the starting point.

Application. Pad both splints as described previously. Use a 2-, 3-, or 4-inch elastic bandages to first secure the padded forearm splint starting at the hand. Once the forearm splint is secured in place, secure the arm portion of the splint beginning at its proximal end.

Forearm and Hand Splints

Volar Splint

(Figure 24.3)

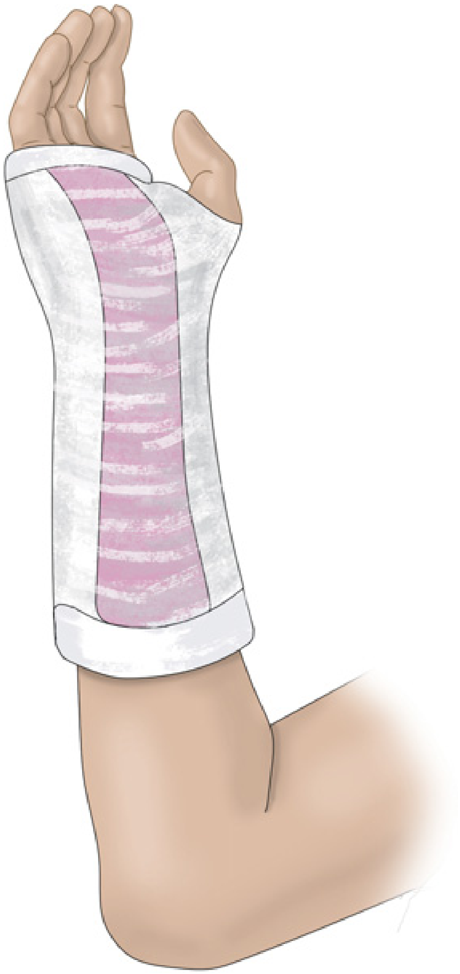


Figure 24.3 Volar splint. Begin the splint in the palm at the metacarpal heads and extend it along the volar surface of the forearm to a point just proximal to the elbow. If any of the fingers are injured, extend the splint to incorporate the involved digits. Place the forearm in the neutral (thumb-up) position, with the wrist slightly extended (10–20 degrees).

Indications. Use a volar splint to immobilize injuries to the hand and wrist. If immobilization of the elbow and/or prevention of pronation and supination of the forearm is desired, then a sugar tongs splint should be used (discussed later).

Construction. Construct the splint with 8 to 10 layers of 3- or 4-inch-wide plaster. The splint begins in the palm at the metacarpal heads and extends along the volar surface of the forearm to just proximal to the elbow. If there is an injury to any of the fingers, extend the splint to incorporate the involved digit or digits.

Application. Apply cast padding as described previously. If the splint is going to incorporate one or more digits, insert a piece of cast padding or gauze between the digits for comfort and skin protection. Place the forearm in the neutral position (thumb-up), with the wrist extended slightly (10 to 20 degrees). Avoid wrist flexion. After properly positioning the wet plaster, fold the sides of the splint up around the forearm to create a gutter effect. Next, fold back the ends of the cast padding and use a 3- or 4-inch elastic bandage to secure the splint in place. Finally, carefully mold the plaster to conform to the contours of the palm and wrist.

Sugar-Tong Splint

(Figure 24.4)

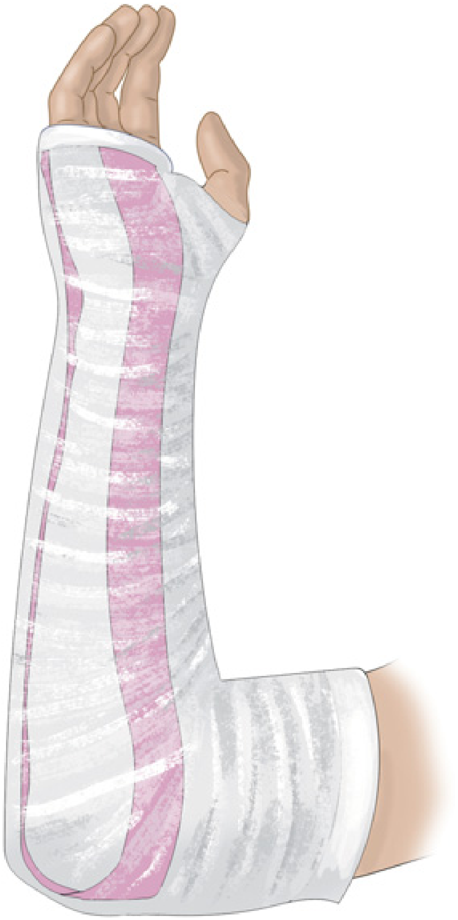


Figure 24.4 Sugar-tong splint. Begin the splint at the metacarpal heads on the dorsum of the hand, extend it along the dorsal surface of the forearm, and then around the elbow. Continue along the volar surface of the forearm and stop at the level of the metacarpophalangeal joints. Keep the elbow flexed at a 90-degree angle, the forearm in the neutral (thumb-up) position, and the wrist in a neutral position or slightly extended (10–20 degrees).

Indications. Use a sugar-tong splint for fractures of the distal end of the radius and ulna when immobilization of the elbow and/or prevention of pronation and supination of the forearm is desired.

Construction and Application. Construct and apply this splint in the same manner as the forearm portion of the double sugar-tong splint described earlier.

Radial Gutter Splint

(Figure 24.5)

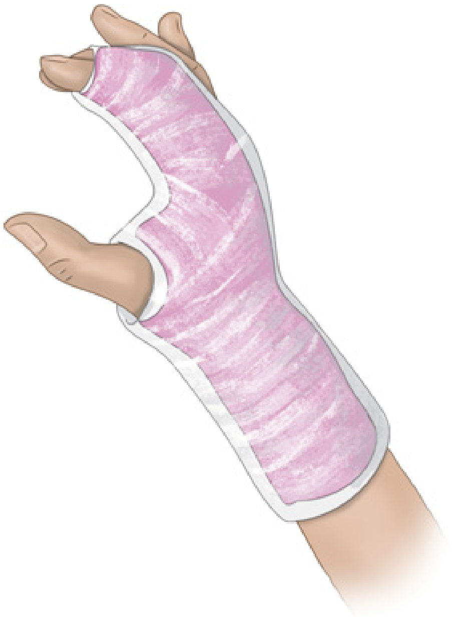


Figure 24.5 Radial gutter splint. The radial gutter splint incorporates both the index and the long fingers. Therefore, Webril or gauze should be placed between the digits to prevent maceration of the skin. Run the splint along the radial aspect of the forearm, from just beyond the distal interphalangeal joint of the index finger of the mid-forearm. Maintain the forearm in the neutral position with the wrist in slight extension (10–20 degrees), the MCP joint in 50 degrees of flexion, and the proximal and distal interphalangeal joints in slight flexion (10–15 degrees). When immobilizing a metacarpal neck fracture flex the MCP joint to 90 degree.

Indications. Use a radial gutter splint to immobilize injuries of the index and long fingers and fractures of the neck, shaft, and base of the second and third metacarpals.

Construction. Make the splint with six to eight layers of 3- or 4-inch plaster. It runs along the radial aspect of the forearm from just beyond the distal interphalangeal joint of the index finger to the mid-forearm level.

Application. Apply cast padding as described previously. Insert an additional piece of cast padding or gauze between the index and long fingers for comfort and skin protection and place the hand and fingers in the *position of function* (Figure 24.6). In the position of function, the forearm is in the neutral position with the wrist in slight extension (10 to 20 degrees), the MCP joints in 50 to 60 degrees of flexion, and the proximal and distal interphalangeal joints in slight flexion (5 to 10 degrees). Place the dry plaster over the extremity and mark the location of the thumb. Cut a hole in the dry plaster to expose the thumb. Dip the plaster and position the wet splint over the extremity. Fold back the ends of the cast padding and secure the splint to the extremity with a 2- or 3-inch elastic bandage. Carefully mold the wet plaster to conform to the patient's hand, wrist, and forearm.

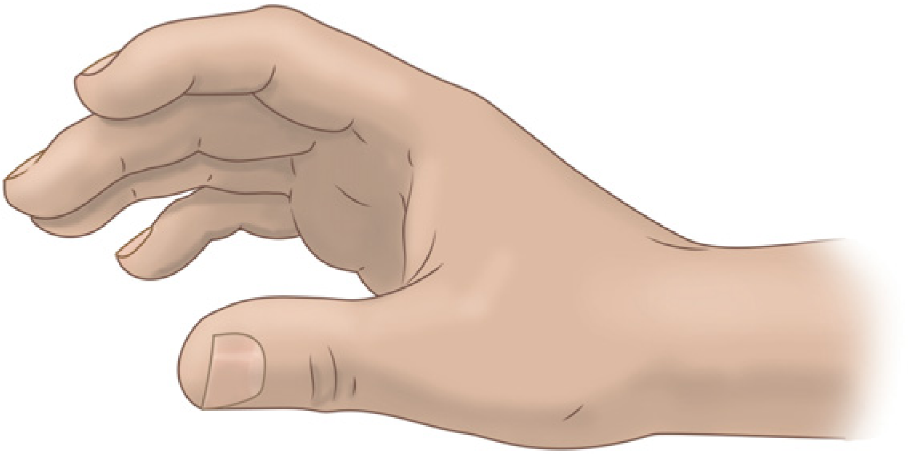


Figure 24.6 Position of function. The position of function is a safe splint position for the hand and fingers for short-term immobilization. The wrist should be in slight extension (10–20 degrees), the metacarpophalangeal (MCP) joints in 50 to 60 degrees of flexion, and the proximal and distal interphalangeal joints to 10 to 15 degrees of flexion and 5 to 10 degrees of flexion, respectively.

Ulnar Gutter Splint

(Figure 24.7)

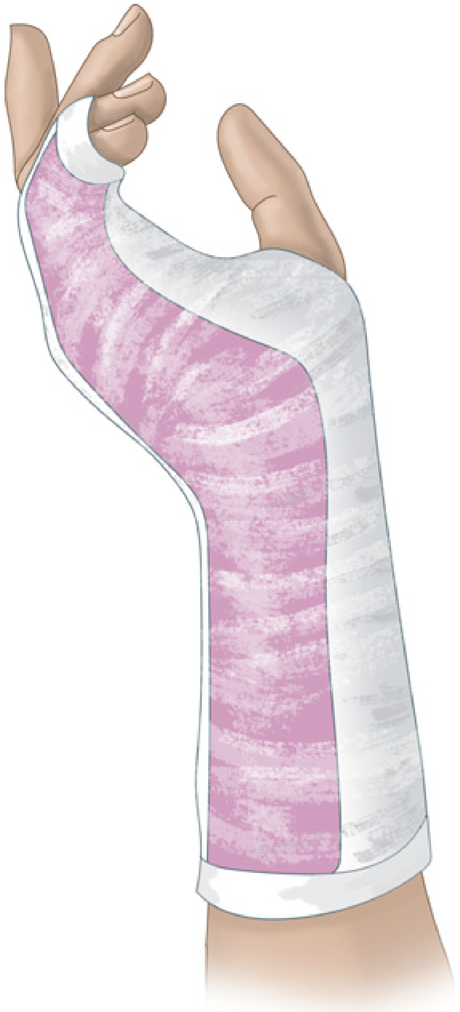


Figure 24.7 Ulnar gutter splint. The ulnar gutter splint incorporates both the little and ring fingers. Thus Webril or gauze should be placed between the digits to prevent maceration of the skin. Run the splint along the ulnar aspect of the forearm from just beyond the distal interphalangeal joint of the little finger to the mid-forearm level. Maintain the forearm in the neutral position with the wrist in slight extension (10–20 degrees), the metacarpophalangeal (MCP) joint in 50 degrees of flexion, and the proximal and distal interphalangeal joints in slight flexion (10–15 degrees). When immobilizing a metacarpal neck fracture, flex the MCP joint to 90 degrees.

Indications. Use an ulnar gutter splint to immobilize injuries to the little and ring fingers and fractures of the neck, shaft, and base of the fourth and fifth metacarpals.

Construction. Make the splint with six to eight layers of 3- or 4-inch plaster. It runs along the ulnar aspect of the forearm, from just beyond the distal interphalangeal joint of the little finger to the mid-forearm level and incorporates both the little and the ring fingers.

Application. Pad the splint as previously described. Place additional cast padding or gauze between the little and ring fingers for comfort and skin protection and place the hand and fingers in the *position of function* (Figure 24.6). Once in proper position, fold the sides of the splint up to form a gutter. Next, fold the ends of the cast padding back and secure the padded split to the extremity with a 2- or 3-inch elastic bandage. Carefully mold the wet plaster to conform to the patient's hand, wrist, and forearm.

Lower Extremity Splints

Traction Splints

Application of a lower extremity traction splint is indicated whenever a fractured femur is suspected. Clinical signs of a fractured femur include thigh pain associated with limb shortening, angulation, crepitus, swelling, or ecchymosis.

Do not use traction splints in patients with pelvic fractures, hip injuries with gross displacement, significant injuries to the knee, or avulsion or amputation of the ankle or foot. The use of traction splints is also not recommended in the presence of an associated distal tibia-fibula or ankle fracture in the same extremity. In these circumstances, the amount of traction required to realign the fractured femur can distract the distal fracture site. A long leg posterior leg splint may be considered in these settings (discussed later).

Regardless of the type or manufacturer, the basic traction splint consists of a metal frame that extends from the proximal thigh to an area distal to the heel. The padded proximal end fits against the ischial tuberosity and serves as the anatomic fixation point. The proximal portion of the splint may be a ring that encircles the proximal thigh, a partial ring, or a padded bar. At the distal end of the splint is typically a ratchet-type device that when engaged, creates traction on the distal femur. All traction splints also have several soft elastic straps that support the thigh and leg.

Commonly used traction splints include the Hare Traction Splint, Kendrick Traction Device (KTD), Sager Emergency Traction Splint, and the Ferno-Trac. Each of these has its own advantages, disadvantages, and unique method of application. For example, traction splints that utilize a half-ring design apply countertraction to the ischial tuberosity, from below the shaft of the femur. This produces flexion at the hip joint of up to 30° and will not allow complete fracture alignment, unless the patient is in a reclining position about 30° from horizontal or the injured extremity is elevated to create the same angle. Traction splints that do not use a half ring do not cause hip flexion (Figure 24.8, Figure 24.9, Figure 24.10, Figure 24.11).

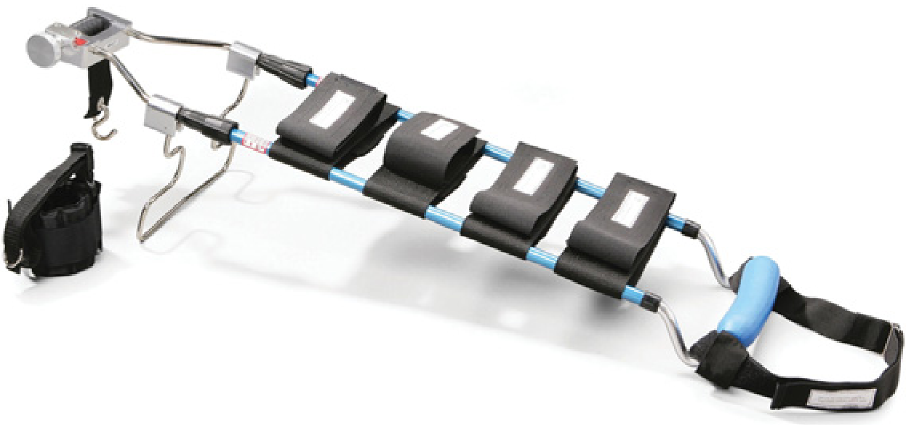


Figure 24.8 Hare Traction Splint.

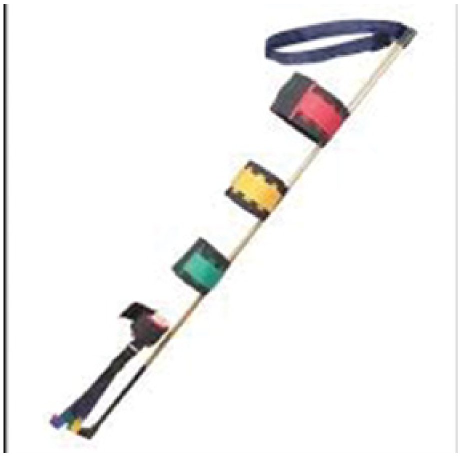


Figure 24.9 Kendrick Traction Device.

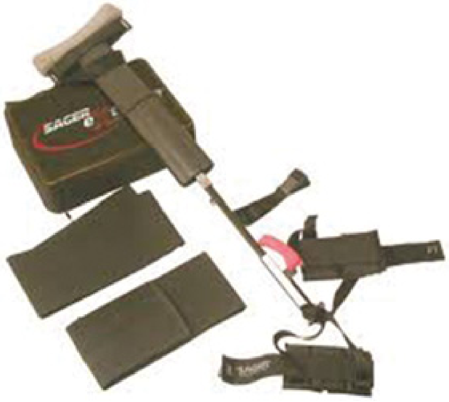


Figure 24.10 Sager Emergency Traction Splint.

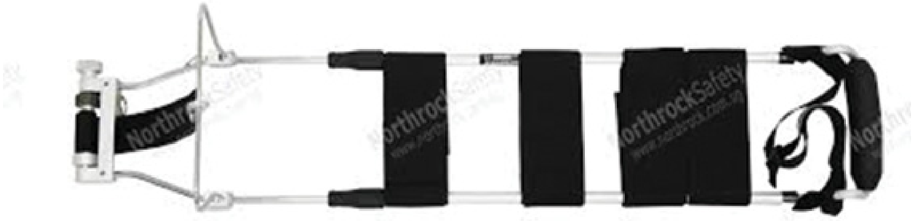


Figure 24.11 Ferno-Trac Traction Splint.

Application. If the splint has an adjustable bar, determine the appropriate length by measuring the uninjured leg. The splint should extend beyond the ankle by approximately 6 inches (15 cm). With the extremity slightly elevated, place the traction splint under the injured leg and rest it firmly against the ischial tuberosity. To ensure that the injured extremity will remain elevated once manual traction has been released, unfold the heel stand and lock it into place. Place the Sager Emergency Traction Splint against the symphysis pubis or laterally against the greater trochanter of the femur. When the padded end of a Sager Emergency Traction Splint is placed in the groin, ensure that the genitalia are carefully protected.

Next, place the ankle harness immediately above the medial and lateral malleoli and attach it to the distal end of the traction splint. Ferno-Trac and other similar traction splints use a ratchet mechanism to apply constant (static) traction to the ankle strap. For Sager-type devices, gently extend the inner shaft of the splint until the desired amount of traction is achieved. The newest Sager model, the SX405, uses a handle to lengthen the inner shaft until the fractured leg is the same length as the uninjured leg. This traction handle also enables providers to set and document the traction force applied. The Sager Emergency Traction Splint is unique in that it provides gentile, quantifiable traction that is dynamic in nature. The dynamic function permits the traction to decrease automatically as the muscle spasm decreases and leg length increases. Regardless of which splint is being used, apply traction gradually to approximately 10% of body weight or a maximum of 15 pounds. Only rarely will more traction be required. The goal is to stabilize the fracture and maintain proper limb alignment; use the least amount of force needed to accomplish this. Finally, place supportive straps around the thigh, knee, and distal leg to vertically stabilize the extremity.

After application of the splint, be sure to recheck distal neurovascular status. The loss of pulses with application of a traction splint requires that the position of straps and the amount of applied traction be reassessed immediately. Also, be sure to recheck the position of the splint and the patient's neurovascular status after moving the patient.

Long Leg Posterior Splint

(Figure 24.12)

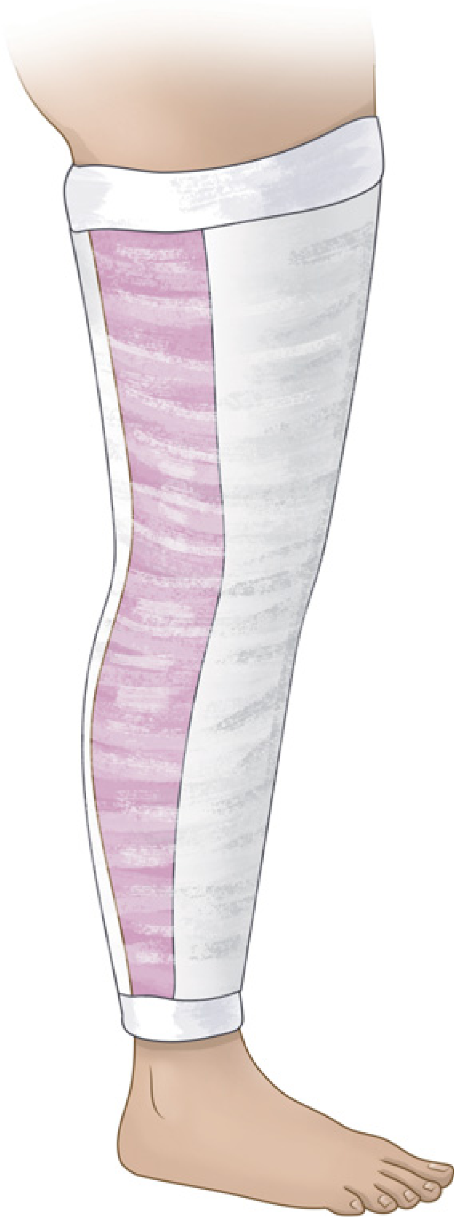


Figure 24.12 Long leg posterior splint. This splint runs from just below the buttocks crease to approximately 5 to 8 cm above the malleoli. The sides of the splint are folded upward to form a gutter configuration. If there is an associated injury to the foot or ankle, the splint can be extended to include the ankle and foot as described for a posterior ankle split in the next section.

Indications. Use a long leg posterior leg splint to immobilize injuries to the knee and foreleg. It can also be used for injuries to the femur when a traction splint is not required or feasible.

Construction. Construct a long leg posterior leg splint with 12 to 15 layers of 6-inch plaster. It should run from just below the buttocks crease to approximately 5 to 8 cm above the malleoli. The sides of the splint are folded upward to form a gutter configuration. If there is an associated injury to the foot or ankle, the splint can be extended to include the ankle and foot as described for a posterior ankle split in the next section.

Application. Apply cast padding as described previously. Have an assistant elevate the leg and hold the splint in place while securing it to the extremity with 4- or 6-inch elastic bandages.

Ankle Splints

Posterior Ankle Splint

(Figure 24.13)

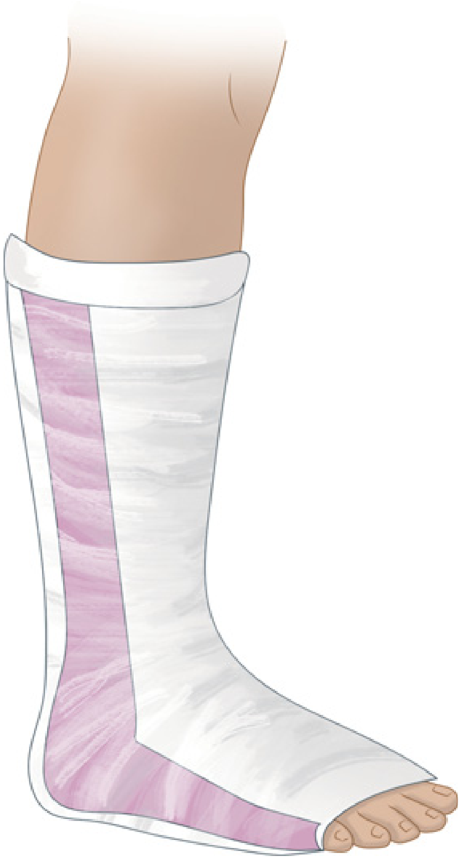


Figure 24.13 Posterior ankle splint. Extend the splint from the plantar surface of the great toe (or metatarsal heads) along the posterior surface of the foreleg to the level of the fibular head. The ankle should be at a 90-degree angle.

Indications. Use a posterior ankle splint primarily to immobilize ankle fractures and reduced ankle dislocations. It can also be used for fractures of the tarsal and metatarsal bones. With particularly severe or unstable injuries, an additional anterior splint may be used to provide extra immobilization resembling that of a formal cast (discussed later).

Construction. Make the posterior splint with 4- or 6-inch-wide plaster strips. It should extend from the plantar surface of the great toe or metatarsal heads along the posterior surface of the foreleg to the level of the fibular head.

Application. Apply cast padding as described previously and have an assistant hold the padded split in place. Use extra padding over bony prominences, particularly the malleoli, and place pieces of cast padding or gauze between the toes if they are to be included in the splint. Fold back the ends of the cast padding and secure the splint in place with one or two 4-inch-wide elastic bandages. Carefully mold the wet plaster around the malleoli and instep to ensure maximum comfort and immobilization. Leave the toes partially exposed for continued examination of color and capillary refill.

Anterior-Posterior Ankle Splint

(Figure 24.14)

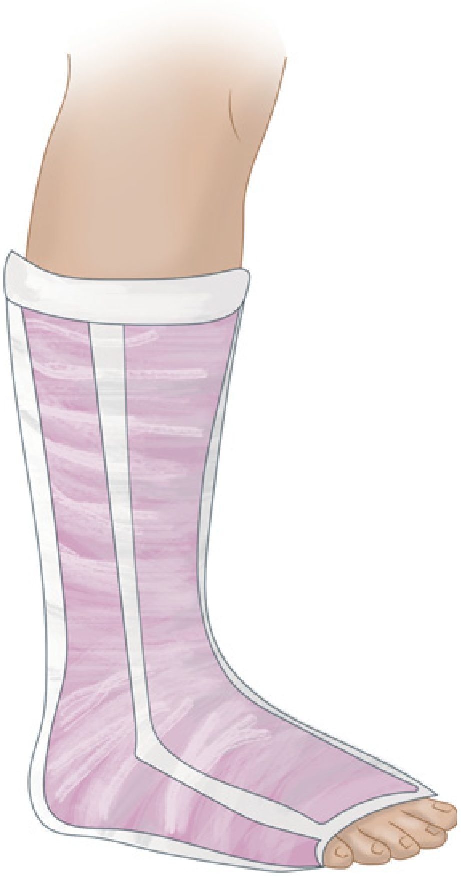


Figure 24.14 Anterior-posterior ankle splint. Apply the posterior splint as described in Figure 13. For the anterior portion, begin on the dorsal surface of the foot at the level of the metatarsophalangeal joints. Extend the splint along the anterior portion of the foreleg to the same height as the posterior splint. Maintain the ankle at a 90-degree angle.

Indications. An anterior splint is never used by itself, but it can augment a posterior splint to create a bivalve effect.

Construction. Cut a piece of plaster several centimeters shorter than the one used for the posterior splint.

Application. Apply cast padding as described previously. After the wet posterior splint has been applied, place the anterior splint over the anterior aspect of the ankle and foreleg parallel to the posterior splint. While an assistant holds both splints in place, secure them with elastic bandages as described earlier for a posterior splint alone. Once secured, carefully mold both splints over the instep and ankle joint.

U-Splint (Stirrup Splint)

(Figure 24.15)

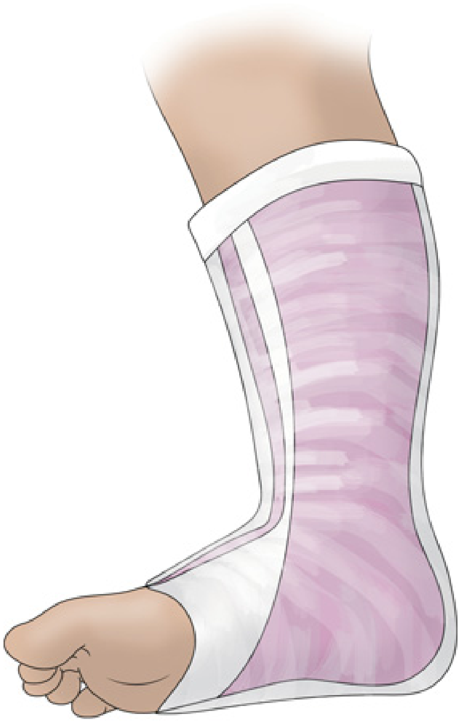


Figure 24.15 U-splint (stirrup splint). Apply the splint under the plantar surface of the foot and extend it up the medial and lateral sides of the foreleg to just below the level of the fibular head. Keep the ankle at a 90-degree angle. For immobilization of the knee, extend the sides of the splint proximally to the groin to create a long leg splint.

Indications. Use a U-splint or stirrup splint primarily for injuries to the ankle. It functions like a posterior splint, and either one provides satisfactory ankle immobilization.

Construction. Construct a U-splint, with 4- or 6-inch-wide plaster strips. The splint passes under the plantar surface of the foot, from the calcaneus to the metatarsal heads, and extends up the medial and lateral sides of the foreleg to just below the level of the fibular head.

Application. Apply cast padding as described previously. Lay the wet plaster across the plantar surface of the foot between the calcaneus and the metatarsal heads with the sides extending up the lateral and medial aspects of the foreleg. Secure it in place with 4-inch elastic bandages. Wrap the elastic bandage around the extremity starting at the metatarsal heads and continuing around the ankle in a figure-of-eight configuration. Once the ankle has been wrapped, use another 4- or 6-inch elastic bandage to secure the remainder of the splint in place. Carefully mold the splint around the malleolus.

Tips and Pitfalls

- Use the palms of the hand to smooth and mold wet plaster. Using the fingers can result in indentations and ridges that can cause discomfort and, if immobilization is more prolonged, pressure sores.
- While rare, limb ischemia can result from splint application. Therefore, frequently recheck the neurovascular status of the injured extremity.
- Plaster can give off a significant amount of heat during the setting process. Risk factors for heat injury are additive and include splint thickness (e.g., more than 12 sheets of plaster), temperature of the dipping water (e.g., greater than 24°C), or placing a pillow under or around the extremity for support during the setting process.
- Complications of traction splints are generally the result of incorrect application and include pain, ongoing hemorrhage, peroneal nerve injury, perineal injury, movement at the fracture site, or further neurovascular compromise.

Chapter

25

Ultrasound in Trauma

Thomas Mailhot and Kazuhide Matsushima

Introduction

Ultrasound offers a quick, repeatable, and moderately sensitive assessment for an important subset of traumatic injuries. The Focused Assessment with Sonography for Trauma (FAST) exam is performed at the bedside without the need to transport a potentially unstable patient away from a monitored setting. The investigation is now incorporated into ATLS guidelines.

FAST and EFAST Exams

The FAST exam involves views of the right upper quadrant, left upper quadrant, suprapubic area, and heart. An assessment is made to determine the presence or absence of intraperitoneal fluid (i.e., hemoperitoneum) and hemopericardium. The extended FAST, or EFAST, also includes thoracic views looking for hemothorax and pneumothorax. The goal of these exams is to detect life-threatening injuries in the primary survey requiring immediate intervention. The FAST/EFAST exams do not assess the retroperitoneum, nor are they designed to detect injuries to specific organs.

Advantages

The FAST exam is performed at the patient's bedside during the primary survey. Unlike CT or comprehensive ultrasound, the patient is not transported out of the trauma bay, thus allowing for uninterrupted monitoring of the patient (Figure 25.1).

Comparison of Selected Diagnostic Tests in Trauma

	Computed Tomography (Chest/Abdomen/Pelvis)	**Extended FAST**	**Diagnostic Peritoneal Aspiration**
Spaces Evaluated	Thoracic Pericardial Peritoneal Retroperitoneal	Thoracic Pericardial Peritoneal	Peritoneal
Ability to Visualize Anatomy	Excellent	Poor	None

Figure 25.1 How various diagnostic modalities in trauma compare in terms of their ability to detect injuries in each of the main compartments of the torso, as well as in their depiction of anatomic detail.

The FAST exam is performed quickly, often in under one minute, and can be repeated as often as necessary should the patient's condition deteriorate, or to detect the evolution of the patient's injuries.

Unlike CT, the FAST exam contains no ionizing radiation – an important concern particularly in vulnerable populations such as pediatrics or pregnancy.

A positive FAST exam leads to more rapid transport of the hemodynamically unstable patient to the operating room, and earlier use of blood transfusion, thus expediting patient care.

Limitations

The FAST is user-dependent; thus an experienced operator might identify a small amount of free fluid that would be overlooked by a novice user.

The FAST exam is not designed to directly identify organ injury. Instead, the FAST looks for the presence or absence of free fluid – a frequent but not universal finding with many specific organ injuries. Furthermore, FAST does not directly assess the retroperitoneum and thus is not designed to evaluate potential blood loss in that compartment.

A number of patient factors can limit the views of the FAST exam, including obesity, bowel gas, and subcutaneous emphysema. In addition, preexisting medical conditions (e.g., ascites, pleural effusions, fluid from a ruptured ovarian cyst) can be detected by the FAST exam and mistakenly assumed to be caused by trauma, prompting surgical intervention when none was warranted. Even small physiologic free fluid such as in a female patient of childbearing age can be seen and misattributed to trauma.

While a positive FAST in an unstable patient is very useful information prompting operative intervention, a negative FAST is not sufficient to exclude important injury. Thus a negative FAST in a stable patient may require CT scan; a negative FAST in an unstable patient may require DPA or further resuscitation in the trauma bay until the patient is stable for CT scan (Figure 25.2).

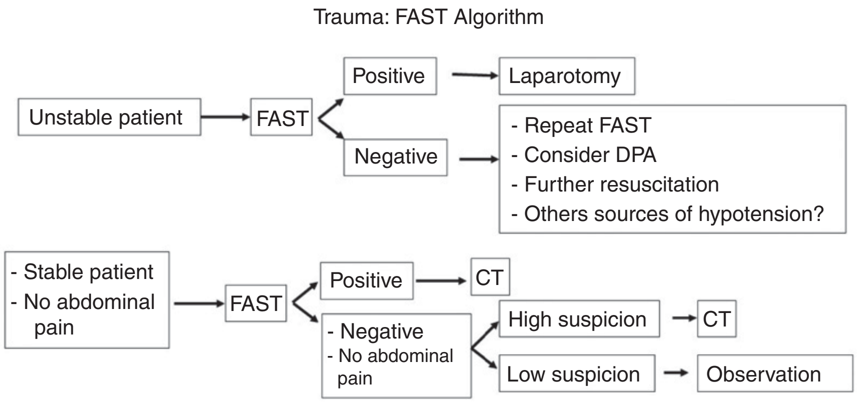

Trauma: FAST Algorithm
Unstable patient
FAST
Positive
Laparotomy
Negative
- Repeat FAST
- Consider DPA
- Further resuscitation
- Others sources of hypotension?
- Stable patient
- No abdominal pain
FAST
Positive
CT
- Negative
- No abdominal pain
High suspicion
CT
Low suspicion
Observation

Figure 25.2 A proposed algorithm for incorporating the results of the FAST exam in trauma patients.

Equipment and Protocol

Both cart-based and boom-mounted ultrasound machines can be used to perform the FAST exam. The boom-mounted option is attractive due to its decreased footprint in the trauma bay, leaving room for other critical tasks such as intravenous access and tube thoracostomy (Figure 25.3).

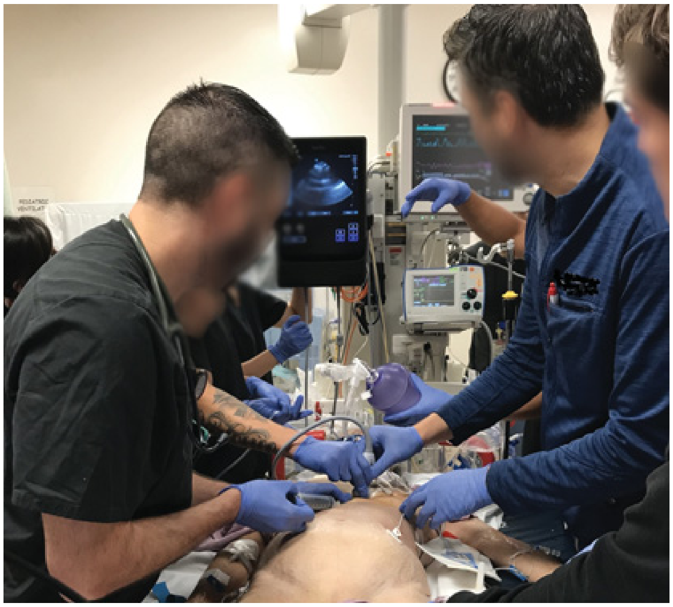
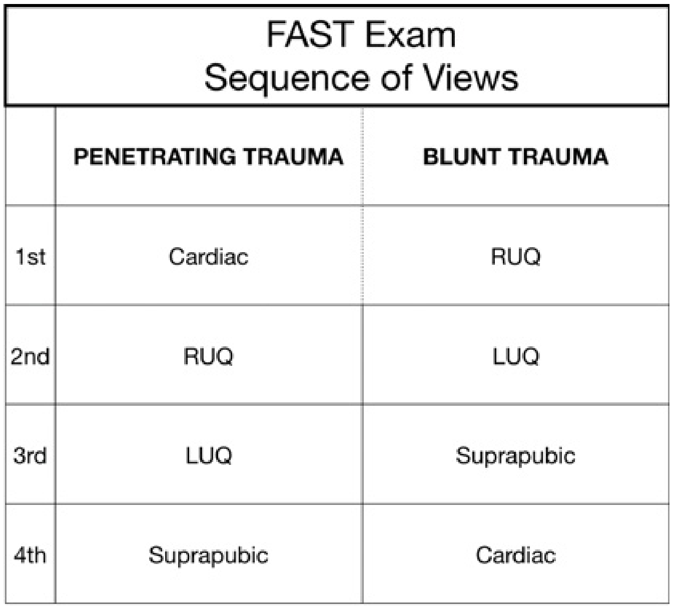


Figure 25.3 Boom-mounted equipment with a "zero footprint" leaves more space at the patient's bedside to perform life-saving procedures and is preferred during a crowded resuscitation. Mounting the machine near the monitoring equipment allows all providers in the room to view and interpret images in real time.

A low-frequency transducer (e.g., curvilinear, phased, or microconvex) with a typical frequency range of 1–5 or 2–5 MHz ensures adequate penetration to visualize intra-abdominal and intra-thoracic structures. Depth settings vary, depending on the patient's size, but typically are set to 20–25 cm.

The sequence of FAST views depends on mechanism of injury sustained by the patient. For penetrating trauma, it is (1) cardiac, (2) right upper quadrant (RUQ), (3), left upper quadrant (LUQ), (4) suprapubic, and (5) lungs. For blunt trauma, it is (1) RUQ, (2) LUQ, (3) suprapubic, (4) cardiac, and (5) lungs. The rationale for this approach has to do with the types of cardiac injuries that are encountered (Figure 25.4).



FAST Exam
Sequence of Views

	PENETRATING TRAUMA	BLUNT TRAUMA
1st	Cardiac	RUQ
2nd	RUQ	LUQ
3rd	LUQ	Suprapubic
4th	Suprapubic	Cardiac

Figure 25.4 FAST exams in penetrating trauma begin with the cardiac view to detect tamponade, requiring emergent operative intervention. In blunt trauma, a cardiac injury is unlikely to result in tamponade; thus the priority is detecting hemoperitoneum.

In penetrating trauma, the heart is the priority because a patient with hemopericardium can rapidly decompensate; thus these injuries must be identified as soon as possible. In blunt trauma, the incidence of blunt cardiac injury producing a survivable injury that can be detected with the FAST is very small.

Individual FAST Views

Right Upper Quadrant View

The RUQ view images the right hemidiaphragm, liver, right kidney, hepatorenal space (Morison's pouch), and caudal liver edge (Figure 25.5 A,B).

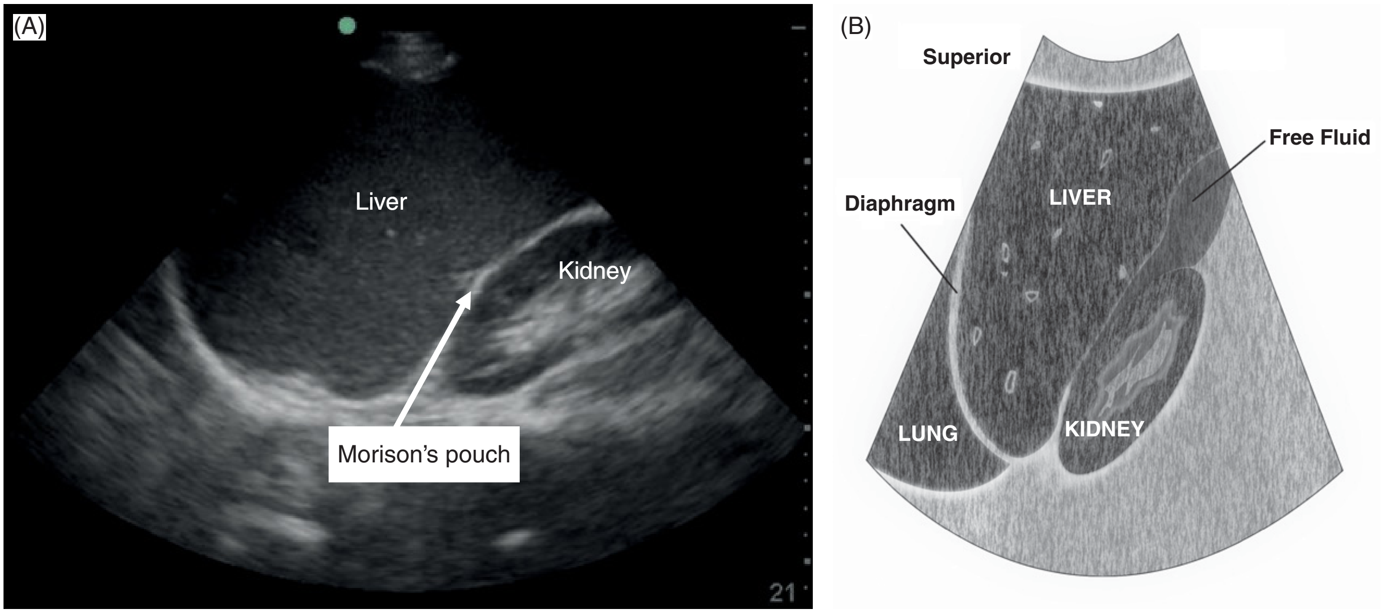


Figure 25.5 A,B Normal RUQ FAST view with diaphragm, liver, and kidney, with Morison's pouch located between liver and kidney. The liver edge is off the screen to the right in this view and requires the operator to slide the transducer caudally (A). Illustration depicting the typical location of free fluid in the RUQ FAST view, starting at the caudal liver tip and progressing into Morison's pouch. A subphrenic fluid collection is rare in trauma and more commonly seen with the large amounts of fluid, as with medical ascites (B).

The earliest place for fluid to appear is at the caudal liver edge, but fluid is often easier to visualize in Morison's pouch. Rarely, fluid may accumulate between the liver and the right hemidiaphragm, but this finding is unusual in trauma and much more likely to be due to preexisting ascites (Figure 25.6 A–C).

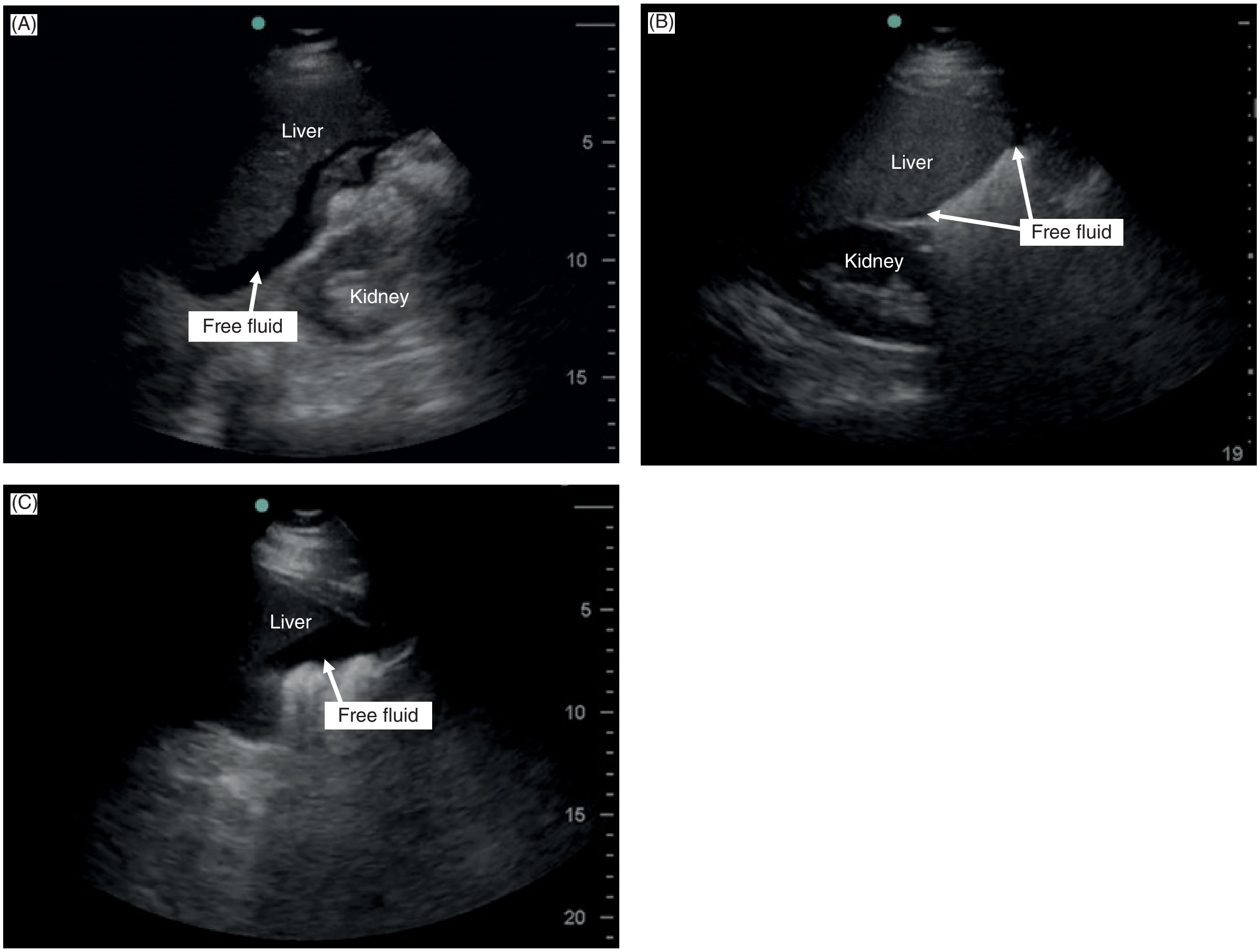


Figure 25.6 A–C RUQ FAST views of three patients showing the variable appearance of free fluid. A 50-year-old male fell from a rooftop, sustaining a grade IV liver laceration and a grade III splenic laceration managed by angioembolization. Large fluid is seen in Morison's pouch (A). A 36-year-old male stabbed in the right upper abdomen. A small collection of free fluid can be seen at the caudal liver tip, with a trace stripe of fluid in Morison's pouch. CT showed laceration of inferior right lobe of liver, and the patient was managed nonoperatively (B). A 39-year-old male involved in a motorcycle collision. Large amounts of free fluid are clearly seen adjacent to the liver tip. This patient had several transverse colon lacerations and omental bleeding discovered at laparotomy, requiring transverse colectomy and partial omentectomy (C).

The gallbladder, inferior vena cava, hepatic veins, and sometimes small bowel are fluid-filled structures that can be mistaken for free fluid. Perinephric fat is typically bright but occasionally can have a darker appearance, which may be misinterpreted.

Left Upper Quadrant View

The LUQ view images the left hemidiaphragm, spleen, perisplenic space, left kidney, and splenorenal space. Because of ligamentous attachments between the spleen and other structures, fluid will not typically be found in the splenorenal space initially. Instead, attention should focus on the space located around the spleen or perisplenic space (Figure 25.7 A,B).

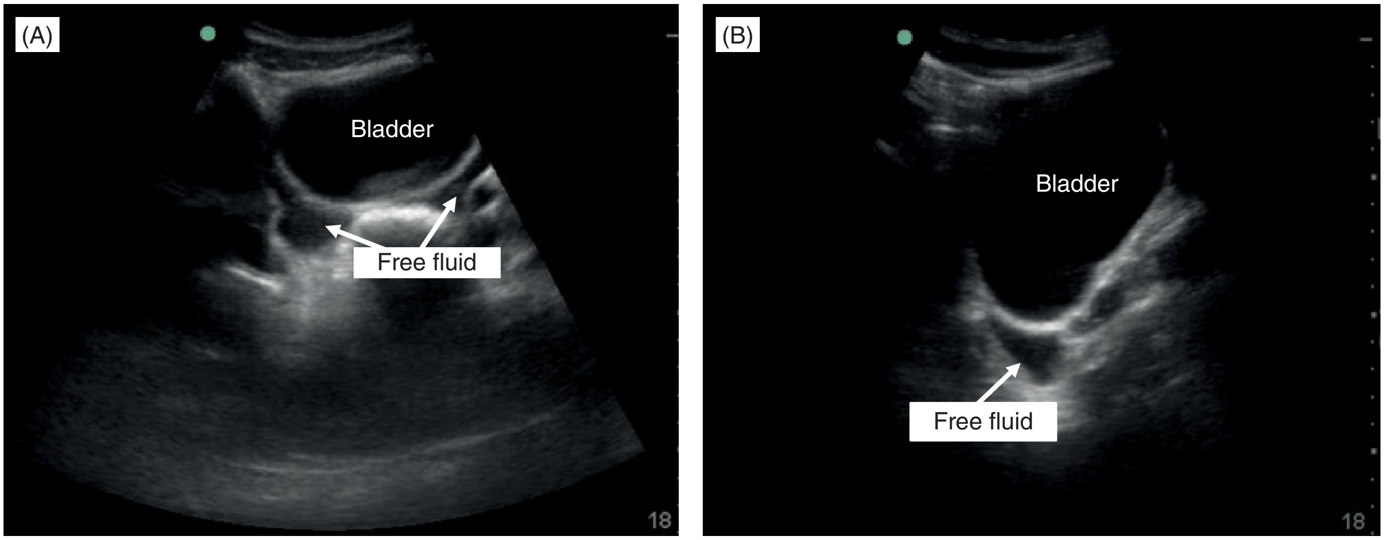


Figure 25.9 A,B Transverse (A) and sagittal (B) suprapubic FAST views with free fluid. Small hemoperitoneum: a triangular anechoic collection on one edge of the bladder posteriorly (A). Small hemoperitoneum: The posterior inflection of the bladder represents the dividing line between intraperitoneal (on the left of the screen) and extraperitoneal (on the right of the screen) bladder (B). Free fluid should only be sought on the intraperitoneal side of the bladder.

The first sign of free fluid in the female patient will be posterior to the lower uterine segment (Figure 25.10).

Suprapubic views rely on the patient having a full bladder; therefore, these views should be obtained prior to a Foley catheter being placed. It is critical to decrease the gain with these views to avoid missing small fluid collections as a result of posterior acoustic enhancement. Several fluid-filled structures in the area may be misinterpreted as free fluid, including seminal vesicles, iliac vessels, and fluid-filled bowel.

It is important to recognize that a small amount of free fluid may be normal in a female patient of childbearing age. A FAST exam in such a patient would be positive, but the FAST does not have the ability to discern whether this is hemoperitoneum or physiologic. It is also now recognized that in a significant minority of pediatric patients (both boys and girls), a small amount of physiologic free fluid can be present.

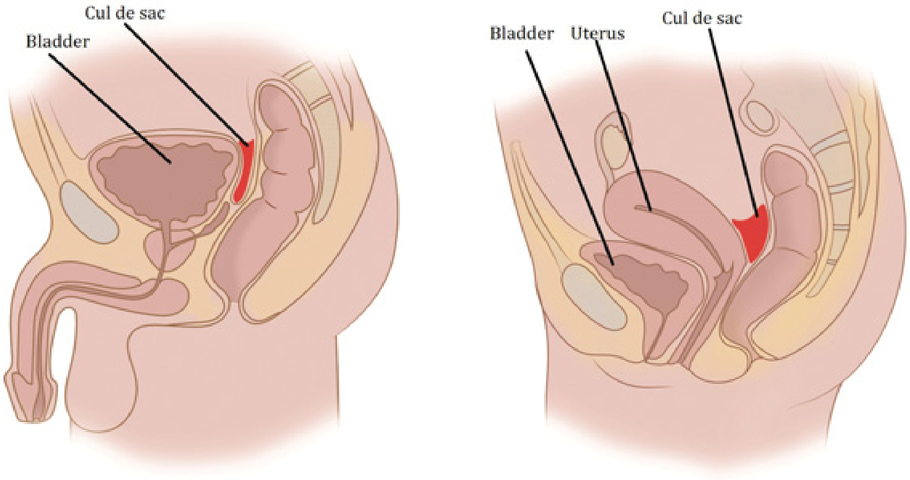


Figure 25.10 Illustration depicting the typical location of free fluid in the suprapubic FAST view in men and women.

Cardiac View

The cardiac view can be obtained from a variety of windows, but the subxiphoid and parasternal windows are the most common. From the subxiphoid position, the important structures to visualize are liver, pericardium, and heart. Pericardial fluid (presumed to be hemopericardium in the trauma patient) will appear between the liver and the right side of the heart, extending around the apex of the heart. From the parasternal view, the heart, pericardium, and descending aorta should be seen. Here, hemopericardium will be seen posterior to the heart. In order to avoid confusing hemopericardium with hemothorax, careful attention must be paid to the location of the fluid relative to the descending aorta: hemopericardium will appear anterior to the descending aorta, whereas hemothorax will appear adjacent to it (Figure 25.11, Figure 25.12).

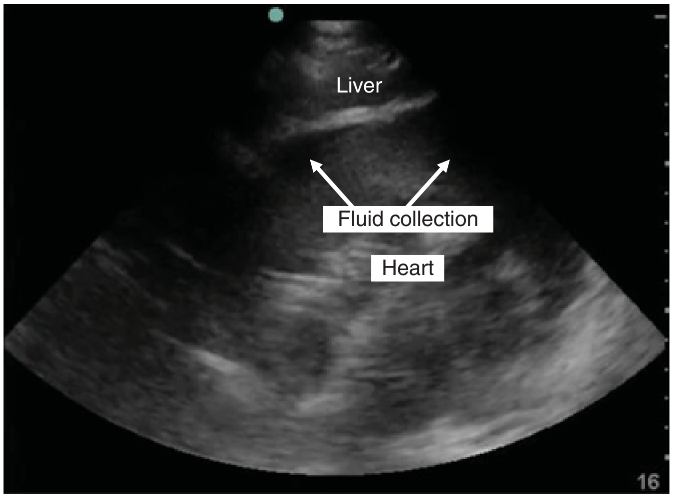


Figure 25.11 Appearance of hemopericardium in the subxiphoid cardiac view of the FAST. A 28-year-old male with stab wounds to chest and back. A circumferential fluid collection is seen between the liver and right heart, and extending around the apex and left ventricle. There is a large clot in the pericardial sac, as well as an apparent soft-tissue defect in the wall of the left ventricle. The patient was taken emergently to the OR, where he was found to have a left ventricular laceration. Even small pericardial fluid collections in the setting of penetrating trauma can quickly lead to cardiac tamponade.

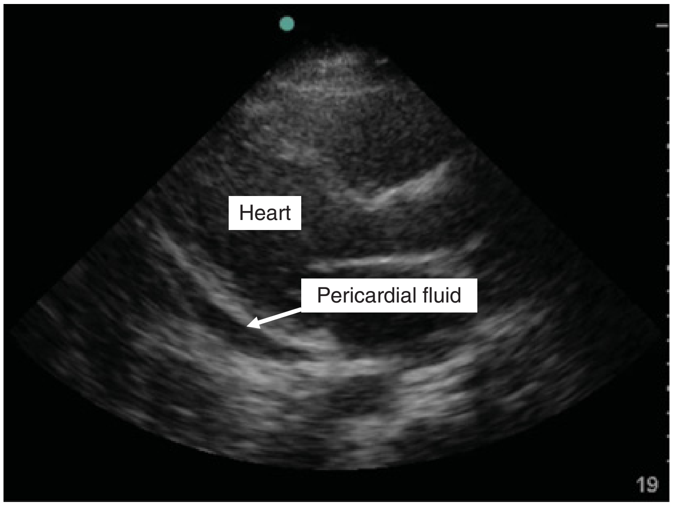


Figure 25.12 Parasternal long-axis cardiac view showing small pericardial fluid. Pericardial fluid collects anterior to the descending aorta.

The subxiphoid view provides the most sensitive assessment for pericardial effusion, but for a variety of reasons, it may not be feasible to obtain. Factors such as body habitus (scaphoid or protuberant abdomen), stomach distension, and abdominal pain may prohibit this view from being obtained. The parasternal window may also be limited by the presence of pneumomediastinum, pneumothorax, chronic obstructive pulmonary disease (COPD), or subcutaneous emphysema.

Thoracic Views

The EFAST introduced thoracic views into the FAST exam, allowing for detection of hemothorax and pneumothorax. Both lateral (hemothorax) and anterior (pneumothorax) transducer positions are utilized.

While assessing the RUQ and LUQ in the traditional FAST exam, the operator moves the probe slightly more cephalad to look into the thoracic cavity. In a controlled setting, ultrasound is very sensitive for the presence of pleural fluid; however, in the less controlled environment of a trauma resuscitation, it may be less reliable. Important structures to visualize are liver (RUQ) or spleen (LUQ), diaphragm, spine/rib cage, and the supradiaphragmatic space, paying attention to mirror artifact. In the absence of pleural fluid, the liver/spleen may appear to be seen both above and below the diaphragm, due to the highly reflective nature of the diaphragm. In the presence of hemothorax, this mirror artifact is not present. Instead, the spine will be seen to extend above the diaphragm in a continuous, straight line (the “spine sign”) as anechoic fluid appears in the supradiaphragmatic space, producing a recognizable costophrenic angle. The size of the hemothorax (small, moderate, or large) can be qualitatively estimated (Figure 25.13).

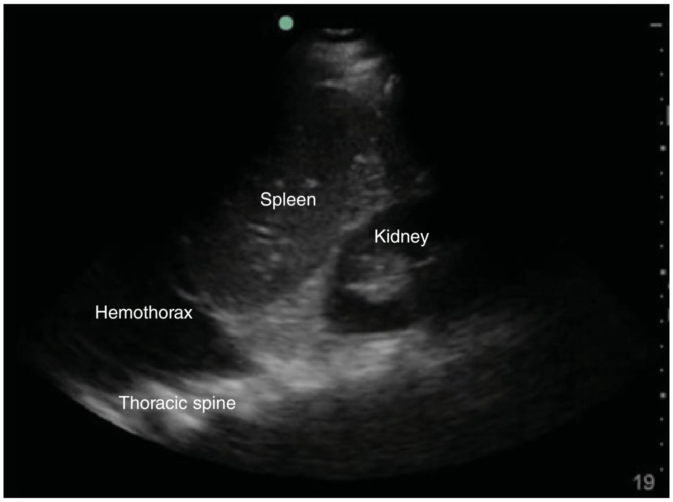


Figure 25.13 Left supradiaphragmatic EFAST view in a 32-year-old male who sustained a gunshot wound to the sternum. A moderate hemothorax is present, seen as anechoic fluid located cephalad to the diaphragm and spleen, with the presence of a spine sign. In order to more accurately quantify the hemothorax, move the transducer cephalad until the hemothorax can no longer be seen and lung tissue prevents the visualization of the spine. CT showed aortic injury at the left subclavian artery, requiring TEVAR.

Sonographic assessment for hemothorax may be confounded by artifact mimicking the spine sign, and avoiding this error requires careful attention to the spine’s trajectory. If the ultrasound transducer is angled incorrectly, the IVC may be mistaken for pleural fluid. Hemoperitoneum is also occasionally misidentified as hemothorax, but careful attention to the location of the diaphragm should prevent this error. Ultrasound cannot reliably distinguish between medical and traumatic effusions.

Placing the ultrasound transducer on the anterior chest allows for rapid detection of pneumothorax. A small pneumothorax may often be missed, but the goal of the EFAST is to detect emergent and hemodynamically significant pneumothoraces. Although switching to a high-frequency linear transducer for this exam provides optimal image quality, this is typically impractical during a trauma resuscitation. The anterior lung views should reveal at least two adjacent ribs, intercostal muscles, and the pleural line comprised of parietal and visceral pleura. Normal lung will demonstrate appropriate "lung sliding," seen in real time as a subtle glistening or twinkling of the pleural line, representing the movement of visceral and parietal pleura relative to one another. In the presence of a pneumothorax, this lung sliding is absent (Figure 25.14).

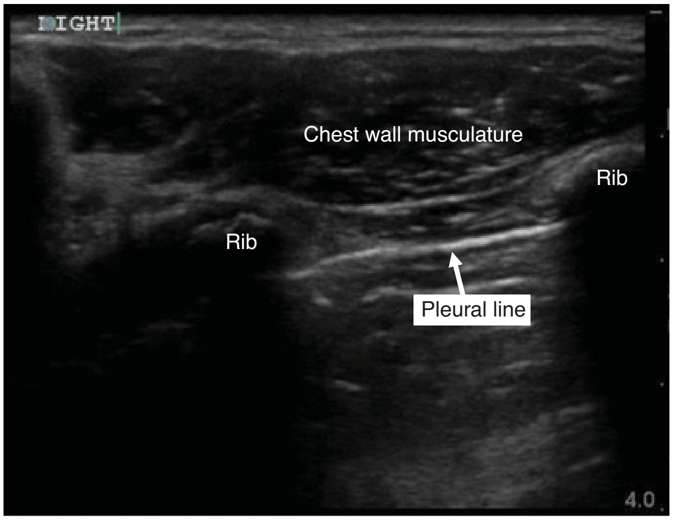


Figure 25.14 Anterior thoracic view of the EFAST exam in a patient with a pneumothorax. The chest wall musculature (pectoralis major, intercostal muscle), ribs with posterior shadowing, and pleural line are seen. The pleural line is somewhat less distinct because it is comprised only of the parietal pleura. In real-time imaging, no lung sliding was detected, consistent with pneumothorax.

M-mode can be used to accentuate the presence or absence of lung sliding: normal lung sliding appears as "waves on a beach," while lack of lung sliding resembles a "barcode sign." A lung point may be seen as an area where both lung sliding (on one side of the transducer) and lack of lung sliding (on the other side) are present; this is virtually pathognomonic for a pneumothorax (Figure 25.15 A,B).

Factors preventing adequate image acquisition include excessive depth and gain, failure to hold the transducer still during the exam, and patient factors (subcutaneous emphysema). There are also other conditions that abolish lung sliding besides pneumothorax, including mainstem intubation, lobar atelectasis, severe pneumonia, acute respiratory distress syndrome, and COPD or pulmonary blebs.

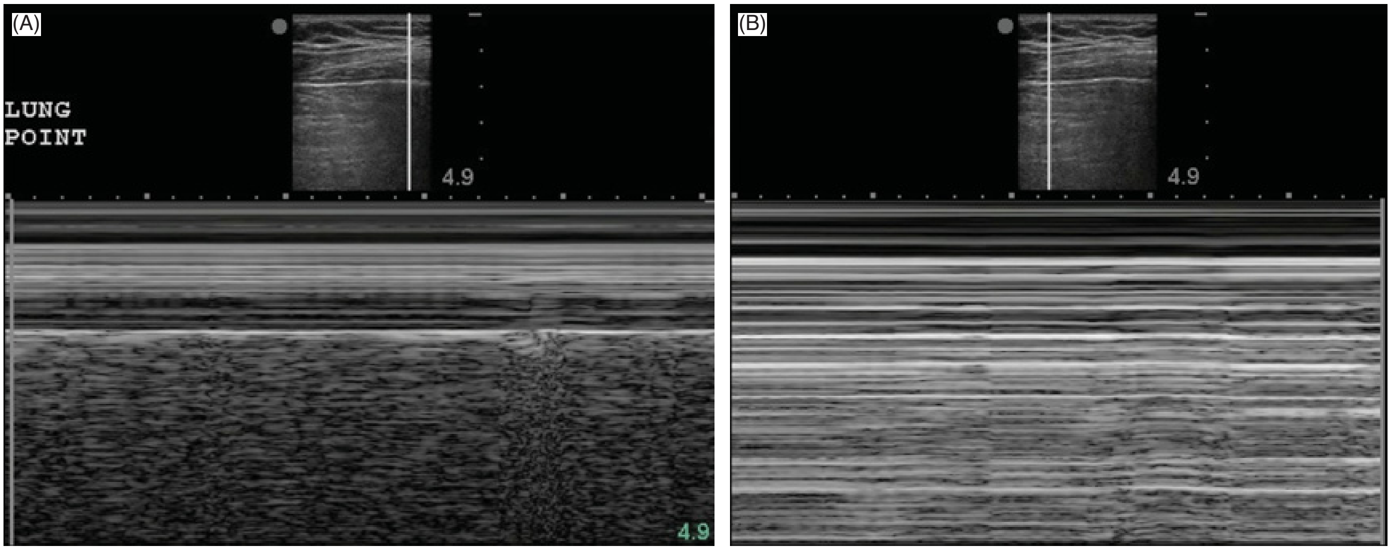


Figure 25.15 A,B A patient with pneumothorax and a "lung point." M-mode images from the same interspace and transducer position, showing seashore sign (A) indicating normal lung seen on the right portion of the interspace, and barcode sign (B) indicating pneumothorax on the left portion of the interspace.

Tips and Pitfalls

- Perform the FAST exam early in the evaluation of the trauma patient, and repeat the exam as needed.
- A negative FAST exam does not exclude significant injury. Further workup with DPA or resuscitation and CT scan might be required.
- A positive FAST exam in a stable patient warrants further imaging (i.e., CT scan).
- A positive FAST exam in an unstable patient warrants operative intervention.
- Be aware of the most common locations to encounter free fluid in each anatomic area.
- Additional thoracic images (EFAST) can be useful to identify hemothorax or pneumothorax.

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